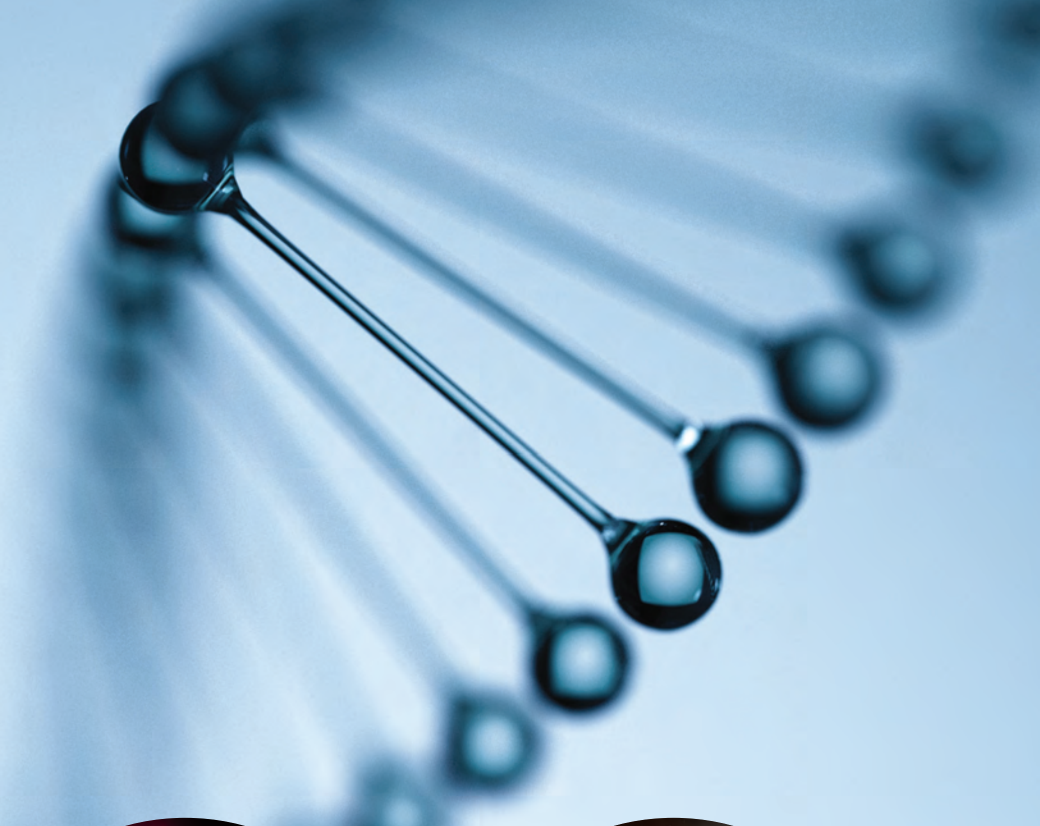
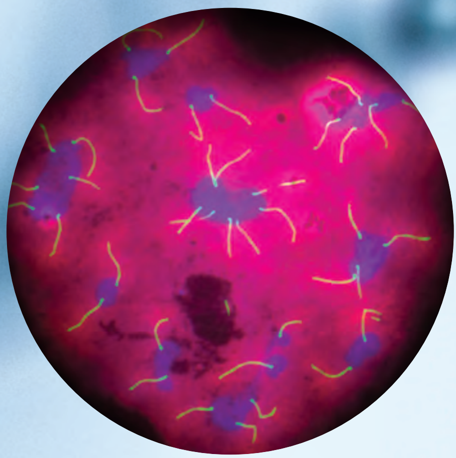
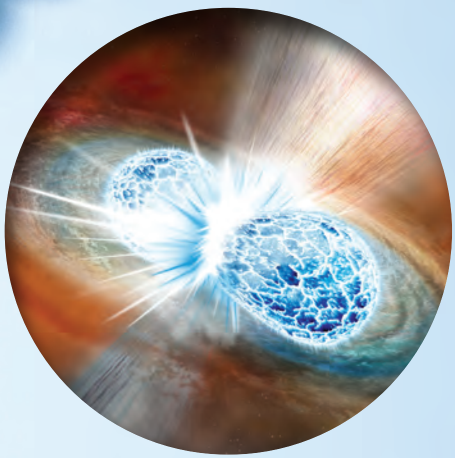
Carnegie Science

2017-2018 YEAR BOOK







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2017-2018 YEAR BOOK

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July 1, 2017 - June 30, 2018

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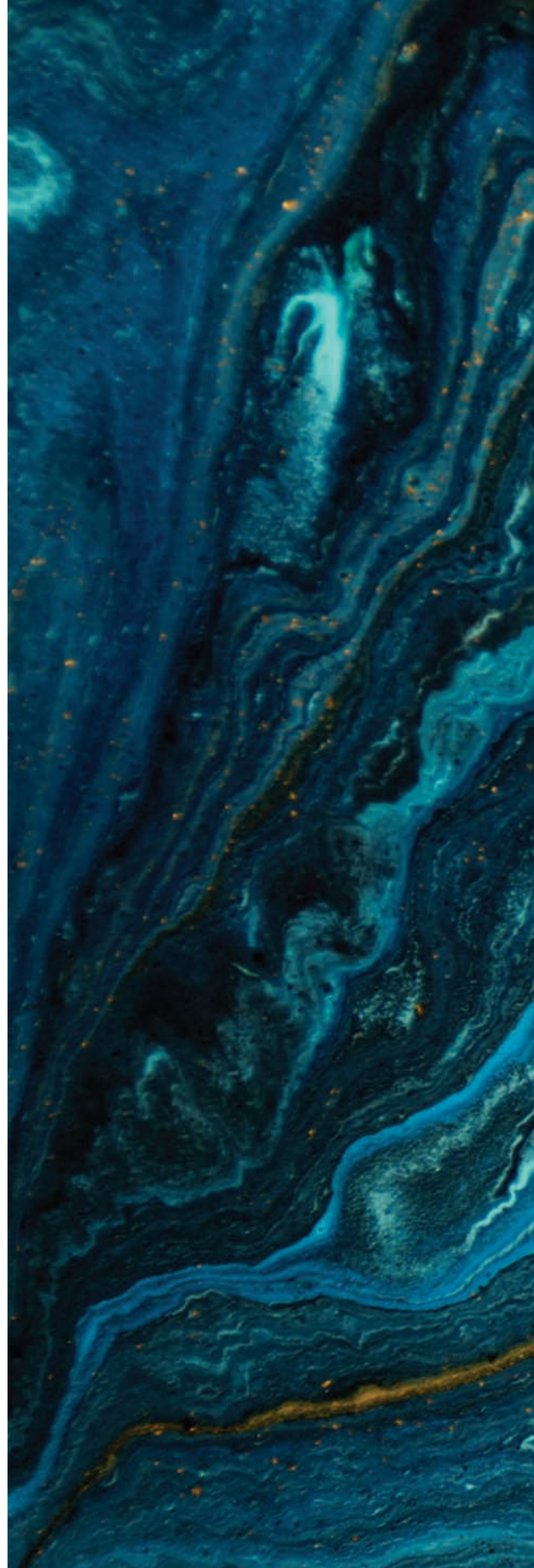

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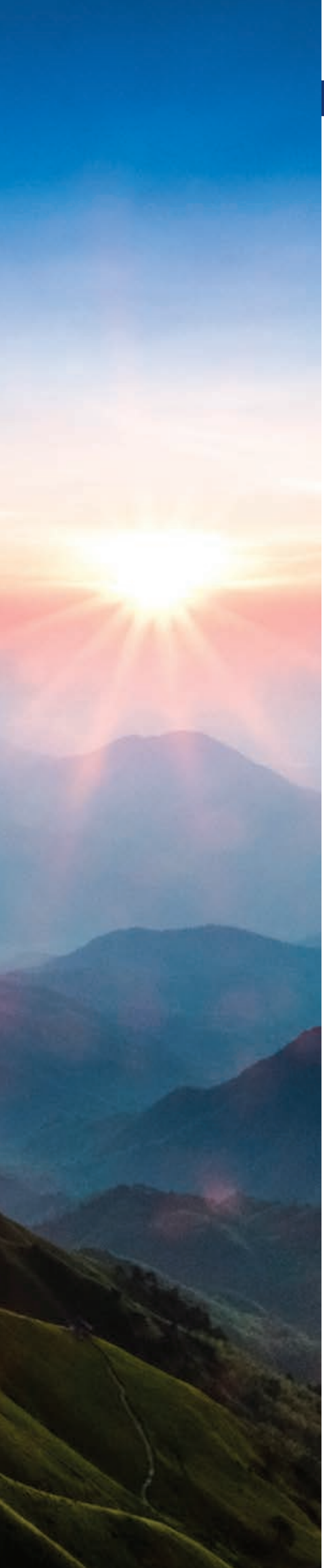
"...I have been deeply impressed by the **intellectual fearlessness of our researchers**, and by the many ways in which that fearlessness leads to potentially **transformative insights and discoveries**."



The President's Commentary

Carnegie president Eric D. Isaacs

Image courtesy Jason Smith, University of Chicago

Carnegie Science is at its best when our scientists chart new directions and ask fundamental questions in a way that is distinctive—sometimes even contrarian. Over these past months, I have been deeply impressed by the intellectual fearlessness of our researchers, and by the many ways in which that fearlessness leads to potentially transformative insights and discoveries.

When the Carnegie Institution for Science was founded more than a century ago, our independent structure was intended to secure our researchers' unfettered ability to seek the truth. In these times, we appreciate Andrew Carnegie's foresight as we watch national funding for basic scientific research fall victim to political and fiscal considerations. So, our institutional responsibility to take risks and address crucial problems in novel ways is now greater than ever.

The wide-ranging work featured in the 2017-2018 *Carnegie Science Year Book* demonstrates the impacts of our scientists' commitment to collaborative, cross-disciplinary, innovative research focused on the betterment of humankind.

Understanding and Protecting Coral Systems

With the specter of climate change threatening our planet's future, it is encouraging to review Carnegie scientists' multifaceted approach to research on coral reefs and the response by these organisms to rising sea temperatures.

Our ongoing research focus on coral reefs reflects the importance of these diverse ecosystems, both in terms of the thousands of species of fish and plant life that reefs support and in terms of the millions of human beings whose livelihoods depend on coral reef fishing and tourism.

By documenting the dramatic changes inflicted on fragile coral ecosystems worldwide due to changing water temperatures and ocean acidification, our researchers are providing more compelling proof of our ongoing climate change challenges. At the same time, Carnegie scientists in our Plant Biology, Global Ecology, and Embryology departments are pursuing inventive strategies with the potential to mitigate the impacts of rising water temperatures and help restore some of these threatened coral communities.

By combining fieldwork on the effects of ocean acidification with laboratory studies of the mechanisms of coral bleaching, our scientists are developing invaluable methods and models that can help us to better understand the underlying genomic and microbial mechanisms involved and perhaps to ultimately protect these vital ocean ecosystems.

At right, researchers at Carnegie's Department of Global Ecology, with colleagues, are studying the effects of climate change on coral reefs at One Tree Island in the Great Barrier Reef of Australia. Rising sea temperatures are a threat to coral communities worldwide. Bleached pillar coral, near Florida, is shown above. Corals have a symbiotic relationship with algae living in their polyps. Rising temperatures kill off the algae, resulting in bleaching.

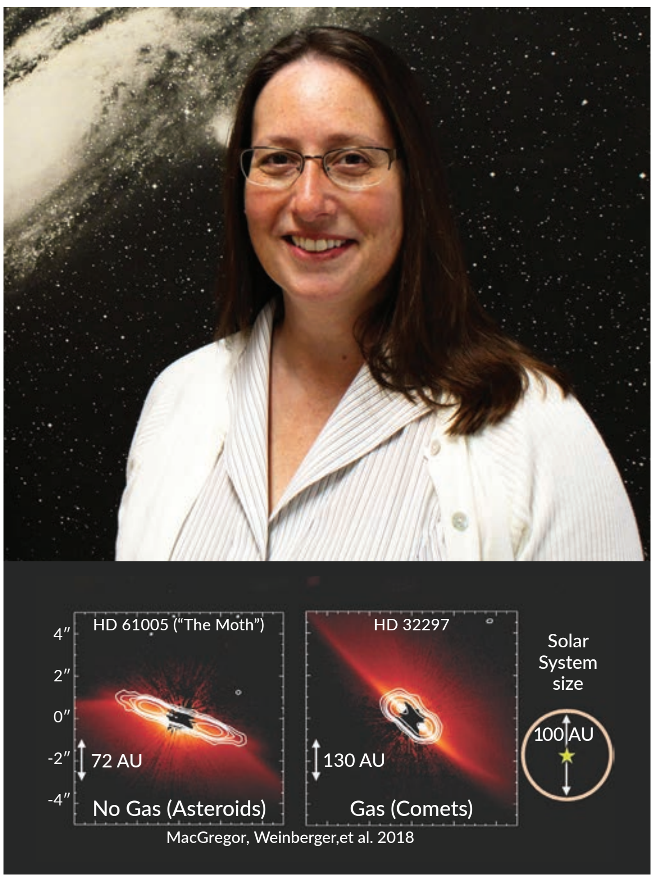
Images courtesy Aaron Takeo Ninokawa, U.C.-Davis and NOAA


YAMAHA

Habitability:
Conditions for Life on Earth and Exoplanets

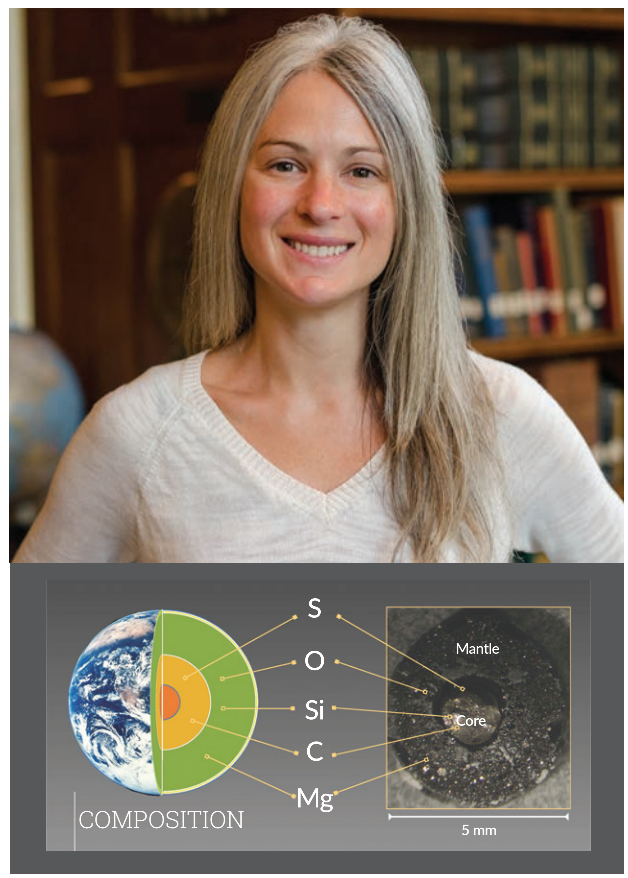
Looking beyond our planet and our Solar System, Carnegie's scientists are pursuing the question of habitability—working at the interdisciplinary boundaries of astronomy, geophysics, geochemistry, planetary science, and astrobiology to understand the planetary conditions that are necessary for life to emerge and flourish.

The search for planets outside our Solar System began in earnest only about 25 years ago. Since then, Carnegie researchers have been leaders in the hunt for evidence of exoplanets; our recent work using computer simulations suggests that there may be an estimated 700 million trillion terrestrial planets in the observable universe. With so many planets swirling through the cosmos, it seems almost implausible that Earth could be the only planet with the capability to sustain life.



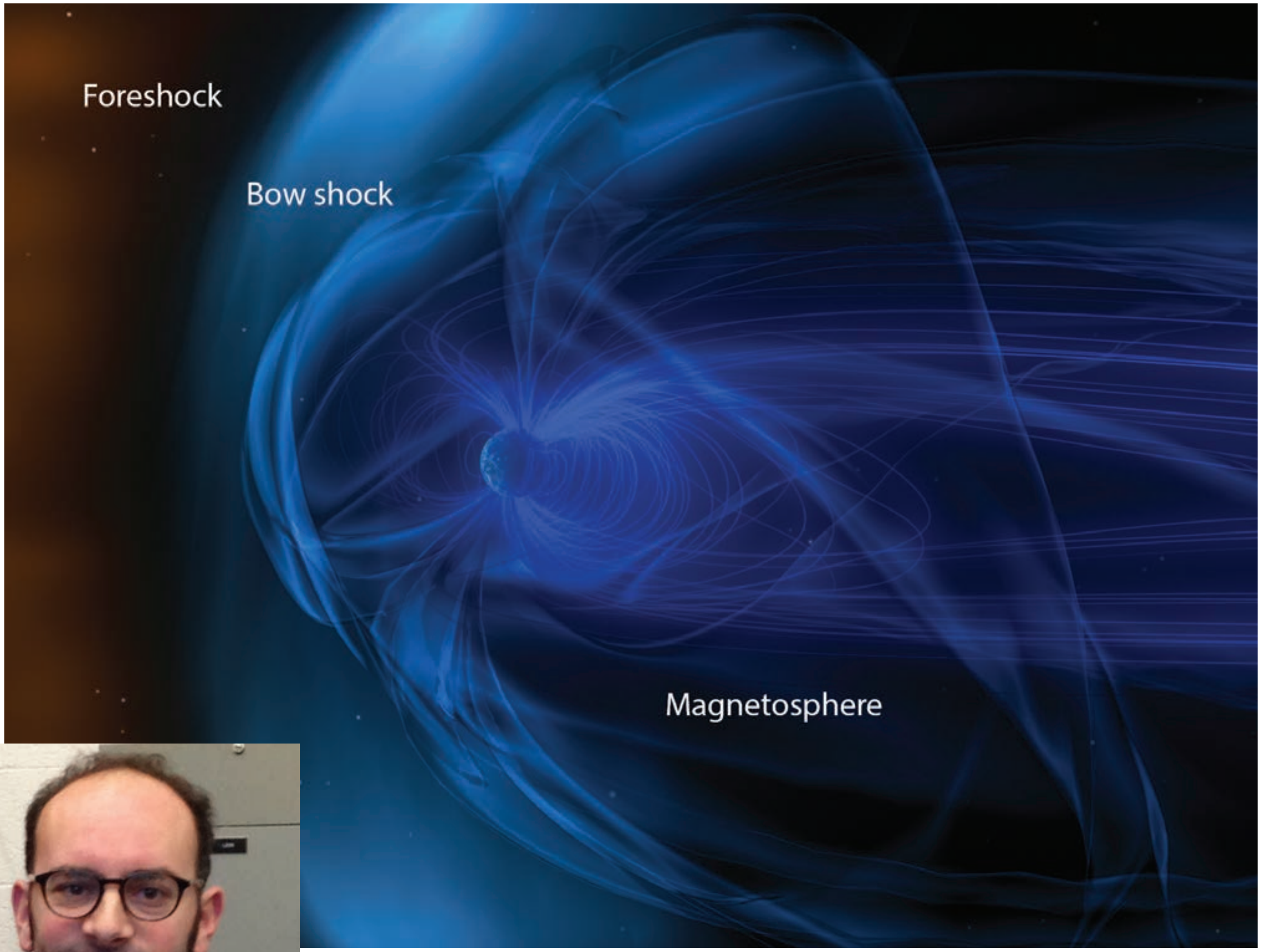
Alycia Weinberger studies how planets form by observing young stars and their disks, from which planets are born. The light from these systems yields information on the existence and abundances of different molecules and conditions, such as temperature and pressure, that are important for understanding what makes a planet habitable.

Top image courtesy Roberto Molar Candanosa; bottom image courtesy Alycia Weinberger and Meredith MacGregor, Carnegie Institution for Science



Anat Shahar simulates conditions in the interior Earth and other planetary bodies using high-pressure methods. Earth's interior contains sulfur, oxygen, silicon, carbon, and magnesium, among other elements—important ingredients for the rise of life on Earth.

Top image courtesy Carnegie Institution for Science; bottom image courtesy Anat Shahar



Peter Driscoll studies the evolution of Earth's core and magnetic field, including magnetic pole reversals. Earth's magnetic field (blue) is generated in the core and protects the planet from solar wind's harmful solar radiation. This protection is essential for life to exist.

Left image courtesy Peter Driscoll; right image courtesy NASA/GSFC

Our inquiry into the likelihood of life on exoplanets focuses on the specific characteristics that enabled development of life on Earth, as a means to discern the aspects of an exoplanet's geologic history, internal dynamics, and surface conditions that would be necessary for extraterrestrial life to arise and flourish. Through this work, our scientists are engaging with a wide range of profoundly intriguing questions: What kept life at bay on Mars and Venus? Does planetary habitability demand geologic factors such as plate tectonics and magnetic fields? Will astronomers be able to detect hints of these processes on other worlds? By looking at these issues through the lenses of multiple disciplines, Carnegie is helping to define a new approach to the age-old questions of where, and how, we can seek life on other worlds.

Celebrating Alumni Achievements

For decades, Carnegie's extraordinary reputation for transformational research has been strengthened by the great contributions made by our postdocs and research associates. During their years at Carnegie, their talent, creativity, and intellectual rigor were fundamental to our work. As Carnegie alumni, their achievements extend our impact worldwide.

In 2018, two of our exceptional postdoctoral alumni won major prizes for their great contributions to science. Professor Tasuku Honjo, who served as a postdoctoral fellow in the Brown Lab at the Department of Embryology from 1971 to 1973, shared the 2018 Nobel Prize in Physiology or Medicine for his discovery of a protein important to the immune system's ability to attack tumor cells. This discovery is fundamental to therapies that have been shown to be particularly effective in fighting cancer.

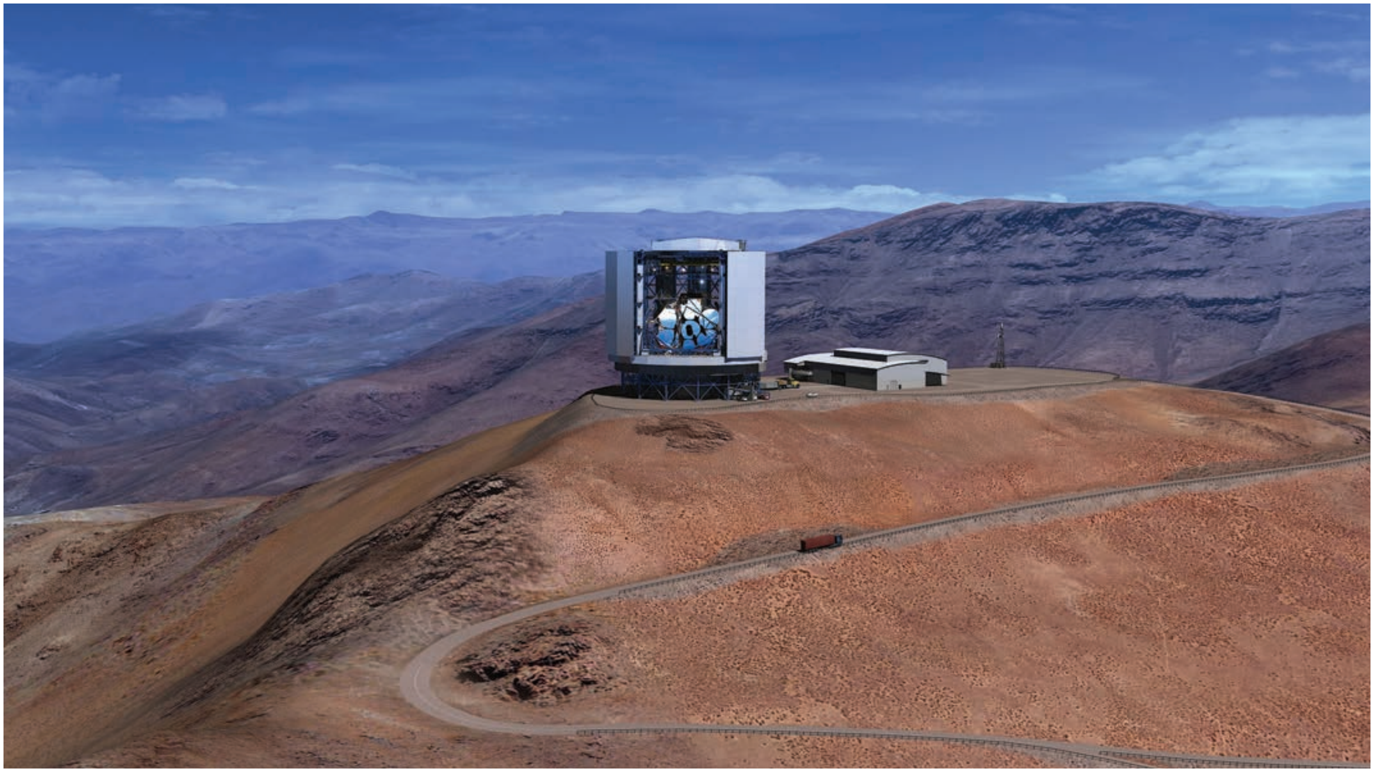
Professor Sarah Stewart, a postdoc in the Geophysical Laboratory in 2002 and 2003, was named a MacArthur Fellow for "her work in advancing new theories of how celestial collisions give birth to planets and their natural satellites." Stewart has proposed that the Earth and the Moon were formed by a synestia—a donut-like cloud of material produced by a high-energy, high-angular momentum collision of two bodies. It could explain why the Earth and Moon have similar chemical compositions and certain aspects of the Moon's orbit.

Tasuku Honjo was a postdoctoral fellow in the Brown Lab at the Department of Embryology from 1971 to 1973. He shared the 2018 Nobel Prize in Physiology or Medicine for the "discovery of cancer therapy by inhibition of negative immune regulation."

Image courtesy Wiki Commons

Sarah Stewart, former Geophysical Laboratory postdoctoral fellow from 2002 to 2003, was awarded a 2018 prestigious MacArthur Fellowship for "advancing new theories of how celestial collisions give birth to planets and their natural satellites, such as the Earth and Moon." Stewart is currently a professor in the Department of Earth and Planetary Sciences at U.C.-Davis.

Image courtesy MacArthur Foundation



This artist's rendition shows what the completed Giant Magellan Telescope will look like. It is located at Carnegie's Las Campanas Observatory in Chile.
Image courtesy Giant Magellan Telescope Organization

Developing World-Leading Tools for Exploration and Discovery

Our ability to explore questions of this magnitude and significance is greatly enhanced by Carnegie's expertise in developing new scientific tools and facilities. From our beginning, Carnegie has been known for our extraordinary telescopes, which have transformed humankind's understanding of the cosmos. Today, we continue to build new instruments that enable us to look even more deeply into the skies, and we are opening new doors to discovery through powerful advances in computing and data analysis.

As a founding member of the Giant Magellan Telescope consortium, Carnegie is working to shape the next class of giant ground-based telescopes, whose collecting power and resolution promise to revolutionize our view and understanding of the universe. Excavation for the Giant Magellan Telescope's massive concrete pier and the foundations for its enclosure has begun on its site at Carnegie's Las Campanas Observatory in Chile, with commissioning of the telescope scheduled to begin in 2025

Carnegie scientists at the Observatories also are leading the fifth generation of the Sloan Digital Sky Survey, continuing this historic effort to create detailed three-dimensional maps of the entire sky. This latest generation will produce optical and infrared spectra of over 6 million objects, including spectroscopic coverage of the Milky Way, and will map black holes using time-domain spectroscopy of quasars and bright X-ray sources.

To extend our scientific leadership in this era of unprecedented data production and collection, Carnegie researchers are developing forefront data visualization techniques to enable deeper analysis of today's large and increasingly complex data sets. Through data visualization, researchers can tease out unsuspected insights and correlations previously obscured by the sheer mass of data.

Looking To The Future

As we embark upon this new chapter in the history of Carnegie Science together, our efforts must be guided by a single fundamental question: what must we do to make sure Carnegie continues to work and discover at the forefront of scientific investigation?

Our answers to this question will be shaped by these central principles:

- We must continue to ask questions that others may be missing.
- We must continue to attract and nurture the best scientific minds.
- We must continue to be recognized as a global leader in science.
- We must preserve the qualities and culture that make Carnegie unique.

Working together, we can build a future of bold, risk-taking science and make sure that Carnegie continues to be known as a place where exceptional investigators work across disciplinary boundaries to answer the biggest questions facing science and to address the greatest challenges confronting humanity.

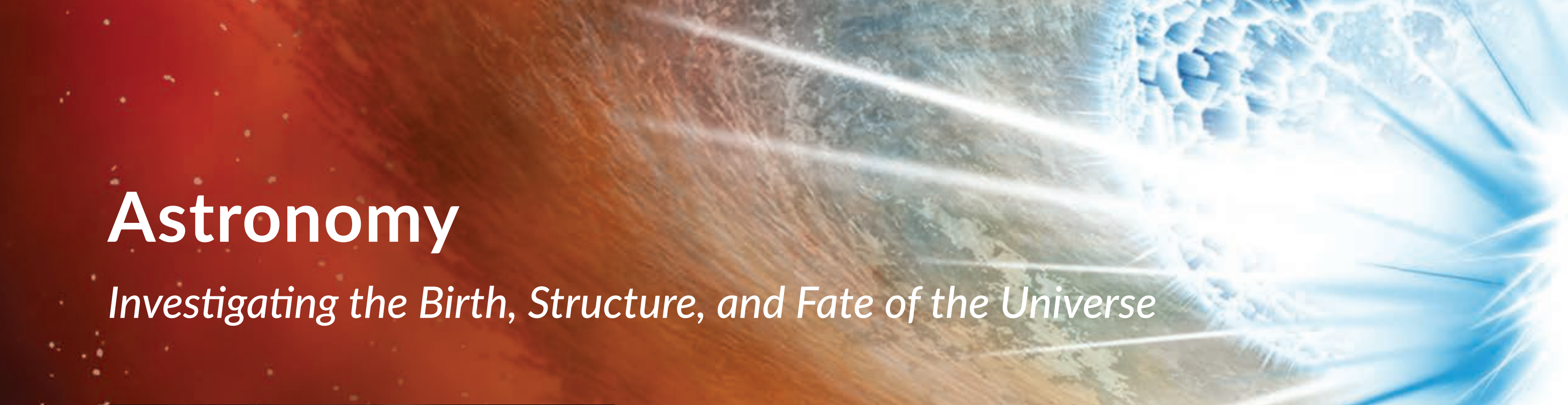
Eric D. Isaacs

President, Carnegie Science

2017-2018 YEAR BOOK

Research Highlights

Image courtesy George Cody



Astronomy

Investigating the Birth, Structure, and Fate of the Universe

This artist's concept shows the explosive collision of two neutron stars.

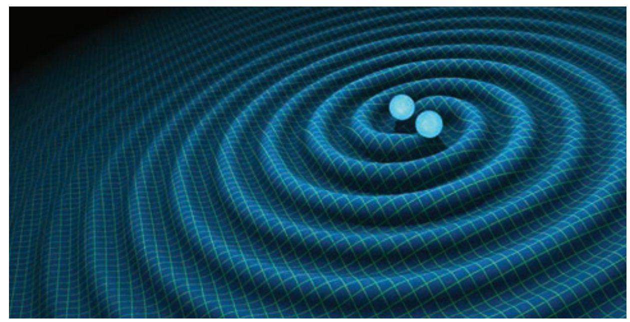
Image courtesy Robin Dienel, Carnegie Institution for Science

"... the first to discover optical light produced by a neutron star merger."

Discovering the First Light with Gravitational Waves

A team led by Carnegie's Anthony Piro, Josh Simon, and postdoctoral fellows Maria Drout and Benjamin Shappee, with colleagues at U.C.-Santa Cruz, were the first to discover optical light produced by a neutron star merger. Studying the same event with both gravitational waves and light ushers in a new era in astronomy of investigating the universe with two completely different probes. This event additionally explains the origin of the universe's heaviest elements, solving a decades-old mystery.

The Laser Interferometer Gravitational-Wave Observatory (LIGO) alerted the Carnegie scientists to the neutron star merger on August 17, 2017. Neutron stars are the dense remnants of massive stars after they die as supernovae. LIGO had previously detected gravitational waves, ripples in space-time, from merging black holes, earning them the 2017 Nobel Prize in Physics. However, black hole mergers do not emit light and are therefore invisible to telescopes. Neutron stars have long been expected to produce both light and gravitational waves when merging, so their detection had been eagerly anticipated.

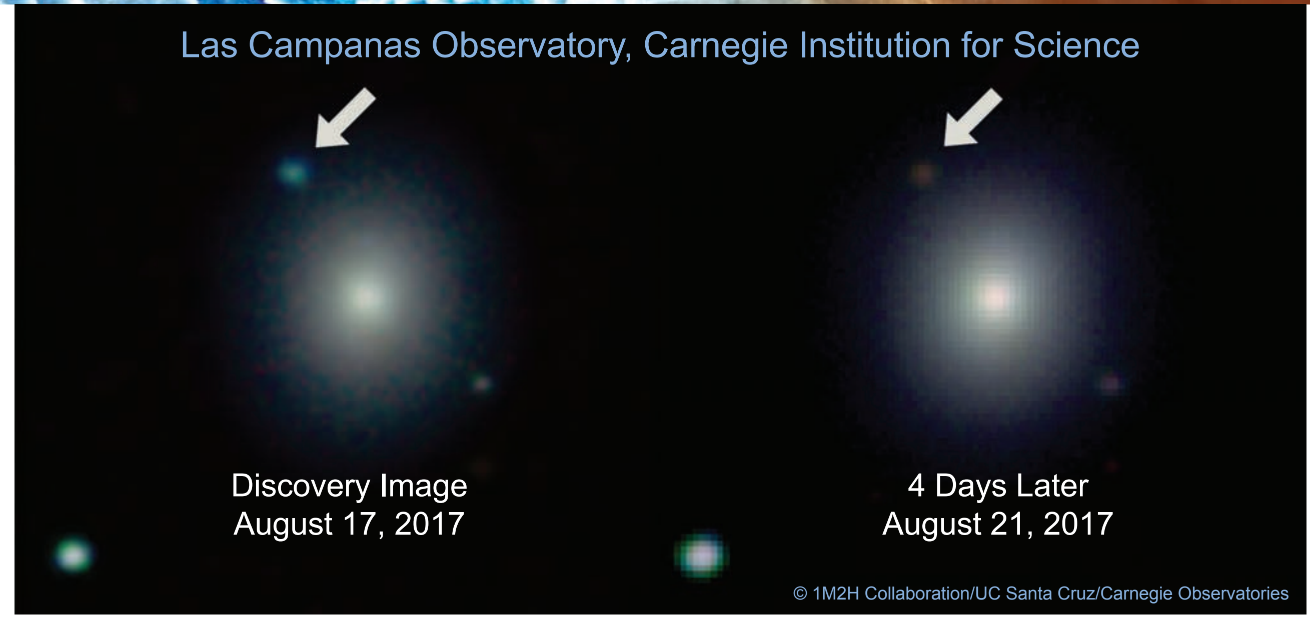


This is an artist's concept of gravitational waves, ripples in space-time, caused by binary neutron stars. Albert Einstein predicted that gravitational waves existed as part of his general theory of relativity a century ago. Only recently have scientists detect any.

Image courtesy R. Hurt/Caltech-Jet Propulsion Laboratory

The group used the Swope telescope at Carnegie's Las Campanas Observatory less than 11 hours after the LIGO alert. Their discovery, named Swope Supernova Survey 2017a (or SSS17a), was the first, despite many large teams across the world feverishly competing to find the elusive event.

Simon and Shappee quickly took additional observations using spectrographs at the observatory's twin Magellan telescopes. Spectra separate light into its component wavelengths, telling astronomers the speed, chemistry, and temperature of the merger material. No other group made comparable observations that first night. Piro, with Carnegie's Juna Kollmeier, performed theoretical work to show the early emission was produced by a shock ripping through the merger debris as the



This image shows a comparison of the neutron star merger discovery, Swope Supernova Survey 2017a (SSS17a), from the night of discovery, August 17, 2017, and four nights later, August 21.

Image courtesy Tony Piro

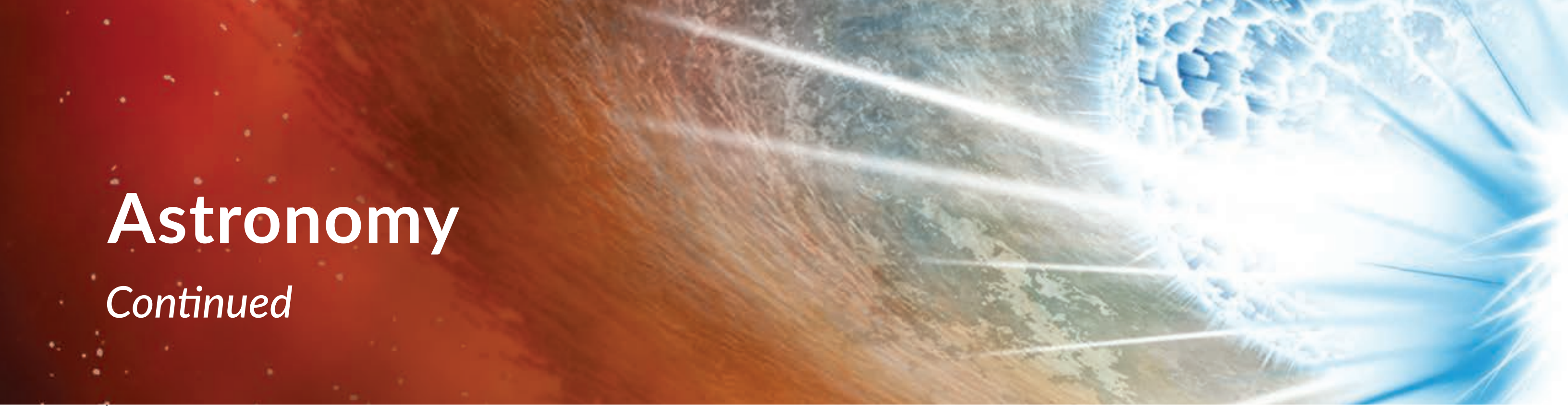
neutron stars collided. This highlights how Carnegie is uniquely positioned to bring theorists and observers together to better understand the universe.

Following their discovery, the Carnegie group continued to observe over the next three weeks. These data revealed a red glow powered by radioactive decay of heavy elements, such as gold, platinum, and uranium, produced in the merger debris. Researchers have long been trying to understand the origin of these elements. With this neutron star merger and detection of the heavy element synthesis, the final piece of this puzzle is now in place.

The journal *Science* named this event the "2017 Breakthrough of the Year."

Members of the discovery team gave a talk about their work to a group of Carnegie trustees and friends. Director of the Observatories John Mulchaey (left) introduced the observing team members: Tony Piro (second), Ben Shappee (third), and Maria Drought (fourth). Theorist Juna Kollmeier (right) was also involved in the work.

Image courtesy Cindy Hunt, Carnegie Institution for Science



Astronomy

Continued

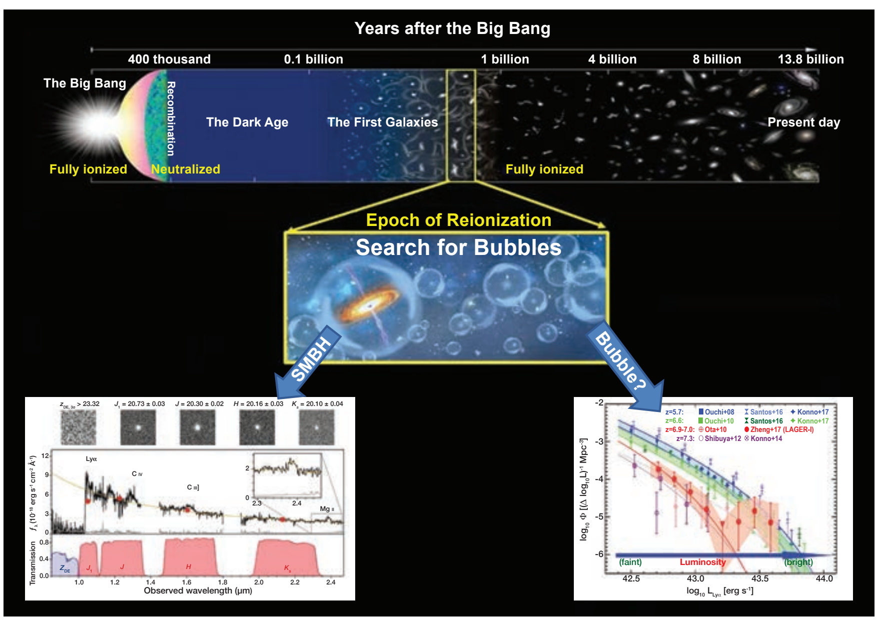
The Youngest, Earliest Galaxies in the Universe

"... the universe and its structures were young, but oddly rich in heavy elements..."

Astronomers recently found oxygen in galaxies that were created just hundreds of millions of years after the Big Bang. Conventional wisdom states that the first generation of stars in galaxies contained only the simplest and lightest elements, hydrogen and helium, with a little lithium and beryllium. Heavier elements were generally formed later in the cores of stars by nucleosynthesis and then dispersed via exploding stars—supernovae.

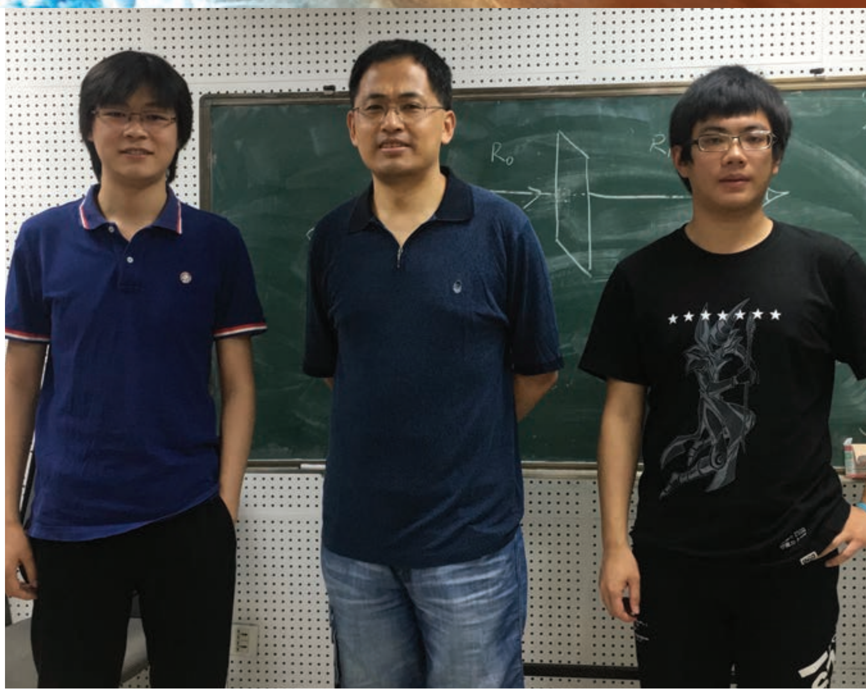
The team, led by Carnegie's Las Campanas Observatory director Leopoldo Infante, discovered a very young galaxy named Tayna, meaning newborn, whose light was emitted when the universe was only 500 million years old. Only a handful of galaxies are known at times before 500 million years, and Tayna is one of the youngest and faintest discovered. They found that it was profusely forming stars containing heavier elements, suggesting that universe did not evolve uniformly.

The Big Bang, some 13.7 billion years ago, produced a hot, murky soup of energetic particles that rapidly expanded. About 400,000 years later, the particles cooled into neutral hydrogen gas. The universe stayed dark until gravity condensed matter into the first stars and galaxies. The energy released caused



At the top, this artwork depicts the current understanding of the evolution of the universe beginning at far left. This new research suggests that early supernovae explosions scattered some heavy elements into the interstellar medium that then reionized; electrons became excited and were lost in differentiated zones or bubbles (middle image). The left plot at bottom shows the wavelengths of light of a very distant and young supermassive black hole (SMBH) quasar. It is imaged at the top of the graphic. The telltale Lyman-alpha (Lyα) signature is at left. The right plot shows the number of sources as a function of brightness of different distant objects measured by different researchers. The red points are this team's measurements. They show an excess at the bright end, which they interpret to be the result of reionization epoch bubbles.

Image courtesy Zhenya Zheng and Leopoldo Infante



Carnegie's Las Campanas Observatory director Leopoldo Infante led the work (left). Team members, from left to right are Weida Hu, Junxian Wang, and Weiyong Kang from the University of Science and Technology of China.

Images courtesy Leopoldo Infante

the neutral hydrogen to excite and lose electrons, a process called ionization. This "reionization" ended some 870 million years after the Big Bang.

Infante with Huan Yang and others are surveying young galaxies from the reionization era employing telescopes at the Cerro Tololo Inter-American Observatory and at Las Campanas, both in Chile. The researchers studied the spectrum of light from the collection of stars in the young galaxies, which had not been observed until now. The light contains information about their chemical composition. In particular, they looked for a spectroscopic fingerprint called a Lyman-alpha emission, which indicates prolific star formation in very distant, young galaxies. The astronomers found evidence that heavier elements were rapidly assembling and were widespread in the early universe.

The observations revealed that the Lyman-alpha emitting galaxies are not distributed uniformly in space. The astronomers believe that the early supernovae explosions scattered some heavy elements into the interstellar medium and that reionization occurred in differentiated zones or bubbles. It is as if the light is making its way through windows scattered in space-time when the universe and its structures were young, but oddly rich in heavy elements and full of electromagnetic and probably gravitational waves.

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Teaching the Art of Teaching Science and Math

"CASE will train over 30 D.C. teachers, who will engage 800 D.C. students in hands-on, laboratory-based learning experiences."

The Carnegie Academy for Science Education (CASE) Gains Support, Wins Competition

In 2017, the Carnegie Academy for Science Education (CASE) was selected to manage the new Amgen Biotech Experience (ABE) site in Washington, D.C. The three-year grant enables CASE to offer extensive professional development, a rigorous biotechnology curriculum, and research-grade laboratory equipment loans to D.C. high school teachers. With Amgen Foundation's support, CASE will train over 30 D.C. teachers, who will engage up to 800 D.C. students in hands-on, laboratory-based learning experiences.

According to an independent evaluation by WestEd, a nonprofit educational agency, students who participate in ABE have substantial gains in biotechnology learning and increased interest in doing science. Change the Equation, a coalition to improve science, technology, engineering, and math (STEM) literacy, distinguished ABE with the highest ranking in STEMworks, its database of effective STEM education programs. CASE is excited to bring real-world lab experiences to Washington, D.C., high school students.

Carnegie Academy for Science Education (CASE) participants conduct biotechnology work in the lab (left and above).
Images courtesy Blonde Photography

In 2018, CASE, the lead partner of the DC STEM Network, was selected out of 92 nationwide entries from 35 states as a winner of the national US2020 STEM Coalition Challenge. The STEM Coalition Challenge seeks to increase hands-on STEM mentoring and maker-centered learning for underrepresented students. Through making, students create new items by tinkering with basic materials, including trash. This hands-on approach is particularly effective for students not interested in traditional STEM classes, due to the real-world applications and problem-solving approach. The DC STEM Network will receive a share of a $1 million award to support further innovative, STEM-based learning for D.C. students.

The DC STEM Network, launched in 2014, convenes more than 250 partners locally and shares best practices with other local and state STEM networks. The Network's mission is to unite partners to design, guide, and advocate for transformative STEM learning opportunities for all D.C. students. The Network has grown to become a one-stop STEM education shop for educators, families, and STEM professionals. CASE transitioned the Network to the next lead agency in late 2018 and will continue expanding CASE student and teacher programs.

The Carnegie Academy for Science Education & Math *for* America

Continued

Math *for* America DC Turns Ten!

Over the last ten years, Math for America DC (M*f*A DC) teachers have reached close to 30,000 D.C. public and charter school students. Founded in 2008 by Carnegie President Emerita Maxine Singer, M*f*A DC includes two programs, the Teaching Fellowship and the Master Teacher Fellowship.

Teaching fellows receive tuition scholarships and a stipend for a one-year master's degree, followed by a four-year teaching commitment in Washington, D.C., public or charter secondary schools. Next year the final 2014 cohort of eight teaching fellows will complete that program.

The Master Teacher Fellowship, which began in 2011, is a five-year program to which experienced secondary school mathematics teachers apply. The program includes stipends and financial support for five years, as well as leadership and professional development opportunities. Master teachers are eligible for special grants to participate in national mathematics conferences. This past year, six mathematics teachers were selected to enter the master teacher program. Beginning in 2019, M*f*A DC will be expanding this program.

Former M*f*A master teacher Bill Day (right) was the 2014 D.C. Teacher of the Year. He currently teaches at E.L. Haynes Public Charter School and has joined the M*f*A DC staff to coordinate the expansion of the master teacher program.

Image courtesy MfA DC

> "…29 alumni of the teaching fellowship have continued teaching mathematics beyond the four-year requirement of the program."

Overall, M*f*A DC has recruited 62 teachers, 37 fellows and 25 master teachers, and retained over 50 to teach D.C., students in public schools. In the 2018-2019 school year, there are eight teaching fellows and 15 master teachers. Over the last ten years, 29 alumni of the teaching fellowship have continued teaching mathematics beyond the four-year requirement of the program. This compares to an average of only up to three years for non-M*f*A teachers in the D.C. public schools.

In 2017, with support from M*f*A DC, master teacher Chris Hoyt became a National Board Certified Teacher (NBCT), which is the most respected professional certification available in K-12 education. Will Stafford, a master teacher since 2012, is also a NBCT. There are only a handful of other D.C. teachers who have obtained this prestigious certification.

In 2018, three MfA teachers presented a session titled "Teaching Social Justice Via Math (and Vice Versa)" at the annual meeting of the National Council of Teachers of Mathematics in Washington, D.C.

With the teaching fellowship program ending and the master teacher program expanding, Bill Day, a former MfA DC master teacher and 2014 D.C. Teacher of the Year, will be joining MfA DC director Bianca Abrams to help coordinate the growing program. The goal is to enroll up to ten master teachers annually.

Master teachers Chris Hoyt (left) and Will Stafford (right) are now National Board Certified Teachers (NBCT). It is the most respected professional certification available in K-12 education.

Images courtesy Chris Hoyt and Will Stafford

"Mathematizing" an Exhibition

At the start of each school year, all MfA DC teachers kick off their professional development with a "mathematizing" event. Mathematizing is the process of understanding, describing, or exploring anything using a mathematical lens. This past year they mathematized at the National Building Museum, including at the exhibition "Making Room: Housing for a Changing America." This exhibition features a 1,000-square-foot home designed to meet the needs of a millennial household. It has movable walls, a super-efficient layout, and furniture with different functions so that the small space meets the needs of diverse occupants with different needs. To mathematize the exhibit, the teachers explored the geometry and other features of the space and expressed them mathematically (e.g., does a "fold-up" apartment really maximize floor space, how many cubic centimeters of chocolate pudding can fit inside the four-sided room, etc.).

After touring the Fun House at the National Building Museum, shown from the outside (top and bottom left), the teachers broke into groups to interpret the different features of the house mathematically (bottom right).

Images courtesy Bianca Abrams, MfA DC

Earth/Planetary Science

Understanding the Formation and Evolution of Planets

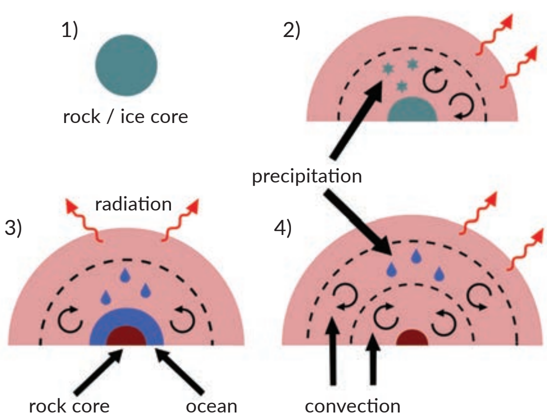
> "The solution may involve dirty snowballs."

Icy Pebbles Make Steam Worlds

The mechanism of gas-giant planetary formation, such as with Jupiter, is a central question in planetary science and for understanding how planetary systems develop, because the gravitational pull from large bodies influences the orbits and growth of smaller objects. The traditional model for gas-giant formation, "core accretion," involves the rapid growth of a solid core to a size, the critical mass, needed to gravitationally capture hydrogen and helium gas from a star's protoplanetary disk. How cores grow to critical mass before the gas is blown away by stellar activity remains an unsolved problem in planet-formation modeling. The solution may involve dirty snowballs.

Carnegie's John Chambers modeled the atmosphere of a planetary core that grows by accreting ice-rich pebbles. He found that the atmosphere goes through several evolutionary stages, and it interacts with the incoming pebbles to cause the critical mass to vary in a complicated way that depends on pebble size, mass flow, and the opacity of dust in the protoplanetary material.

When the planet's core reaches about 0.002 Earth masses, it begins to acquire an atmosphere. The atmospheric mass increases rapidly with increasing core mass. The outer atmosphere becomes thin, with nearly constant temperatures, and energy is transferred by electromagnetic radiation to space. Close to the core, temperatures increase and a convective zone develops, where hotter material rises and colder falls.



This schematic shows evolutionary stages of a protoplanet accreting ice-rich pebbles. First, a rocky core arises, but the atmosphere is lost to space. Second, the planet begins to retain an atmosphere surrounding the solid ice/rock surface. Energy in the outer atmosphere radiates out. Energy in the inner atmosphere moves via convection, with ice grains precipitating toward the surface. Third, the planet forms an ocean on the rocky core. The outer atmosphere is still radiative, while the inner atmosphere moves heat by convection with ice and water precipitation. Fourth, the planet is similar to stage three, but precipitation occurs at middle altitudes. The deeper atmosphere is now too hot for water to condense.

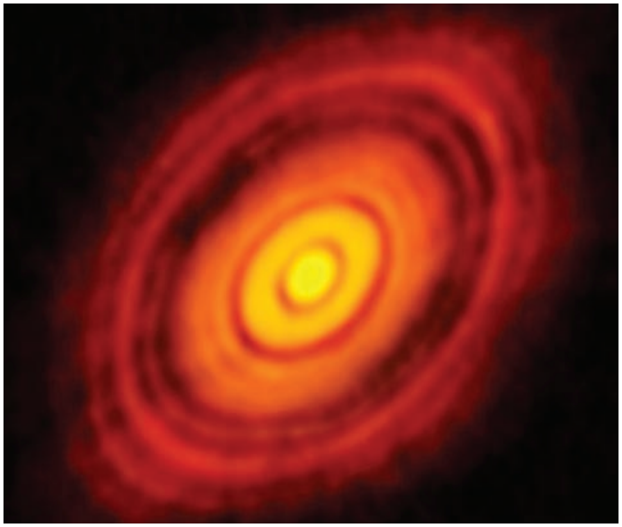
Image courtesy John Chambers

Carnegie's John Chambers modeled the atmosphere of a planetary core that grows by accreting ice-rich pebbles.

Incoming pebbles slowly sink through the atmosphere. As pebbles react in warmer regions, the ice evaporates, saturating the atmosphere with steamy water vapor. Water and ice precipitate toward the core, forming an ocean, when the core reaches about 0.04 Earth masses, and temperatures and pressure allow water, ice, and vapor to coexist.

In the atmospheric convective region, water vapor in the saturated gas condenses as the gas rises and cools. When the rocky core mass reaches about 0.08 Earth masses, the interior temperature becomes too high for an ocean to exist. The water becomes a supercritical fluid that is mixed with hydrogen and helium gas accreted from the protoplanetary disk.

The complicated evolution of atmospheric structure means that the critical mass for gas accretion varies with the details of pebble accretion. Chambers found that the core mass for an atmosphere of 50% hydrogen and helium might be a better indicator of the onset of gas accretion than the core mass alone. This mass is typically 1-3 Earth masses for pebbles that are 50% ice.



This image, from the Atacama Large Millimeter/submillimeter Array (ALMA) radio telescope, shows a gas-rich protoplanetary disc around a young star named HL Tauri in the constellation Taurus. The substructures of the disc are particularly detailed.

Image courtesy ALMA, European Southern Observatory, National Astronomical Observatory, National Radio Astronomy Observatory

Questionable Habitability of Proxima b

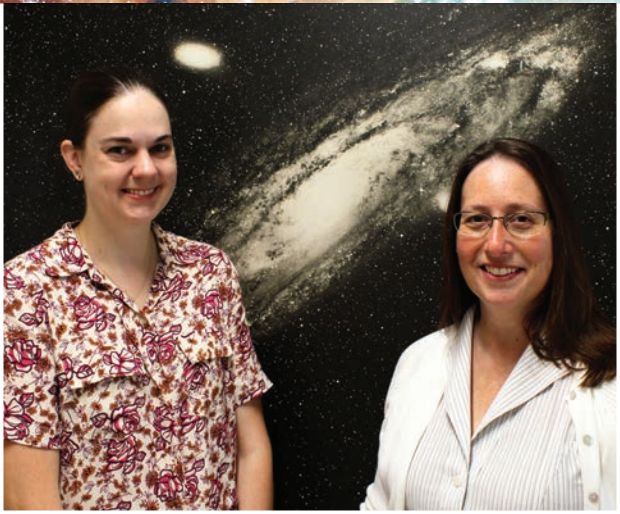
A team of astronomers led by Carnegie's Meredith MacGregor and Alycia Weinberger detected a massive radiation explosion, a stellar flare, from the closest star to our Sun, Proxima Centauri. The observation raises questions about the habitability of our nearest exoplanet, Proxima b, which orbits Proxima Centauri.

MacGregor and Weinberger, with colleagues, discovered the enormous flare when they reanalyzed last year's observations by the Atacama Large Millimeter/submillimeter Array (ALMA), a radio telescope with 66 antennas.

At peak, the flare was 10 times brighter than our Sun's largest flares observed at similar wavelengths. Stellar flares have not been well studied at those wavelengths, especially around otherwise normal M dwarf stars like Proxima Centauri.

The researchers used data from the Atacama Large Millimeter/submillimeter Array (ALMA), the largest radio telescope in the world. ALMA is composed of 66 antennas; some are shown here. ALMA is located in the Chajnantor Plateau in the Atacama Desert, one of Earth's highest and driest places.

Image courtesy European Southern Observatory



Postdoctoral fellow Meredith MacGregor (left) and staff scientist Alycia Weinberger conducted the work on Proxima b.

Image courtesy Roberto Molar Candanosa, Carnegie Institution for Science

The flare increased the star's brightness 1,000 times over 10 seconds. It was preceded by a smaller flare. Together, the event lasted fewer than two minutes of 10 hours of ALMA's observations of Proxima over many weeks.

Stellar flares happen when a shift in the star's magnetic field accelerates electrons to almost light speed. The electrons interact with highly charged plasma, causing an eruption across the electromagnetic spectrum

The Proxima b planet was likely blasted by the extreme radiation flaring from its star. The star was already known to experience regular X-ray flares. Over billions of years since forming, large flares could have evaporated any atmosphere or ocean on Proxima b and sterilized the surface, which means

"The Proxima b planet was likely blasted by . . . its star."

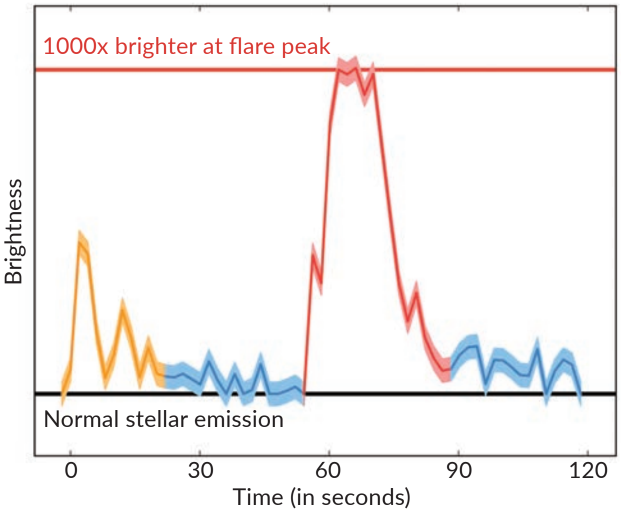
This artist's impression of a flare from the star Proxima Centauri is modeled after the loops of glowing hot gas seen in the largest solar flares. The exoplanet Proxima b is in the foreground. Proxima b orbits its star 20 times closer than the Earth orbits the Sun. A flare 10 times larger than a major solar flare would blast Proxima b with 4,000 times more radiation than the Earth gets from solar flares.

Image courtesy Roberto Molar Candanosa/Carnegie Institution for Science, NASA/Solar Dynamics Observatory, NASA/Jet Propulsion Laboratory

habitability involves more than just being the right distance from the star for liquid water to exist. M stars are the most common type of star in the galaxy, and they have a higher incidence of small planets over Sun-like stars. If others behave like Proxima, the outlook for galactic life would be poor, at least around M stars.

Other researchers looked at these same ALMA data for its average brightness and included the light of both the star and the flare. The extra flare light caused them to infer multiple disks of dust encircling Proxima Centauri, similar to our asteroid and Kuiper belts. Dust belts suggest more planetary bodies in the system.

When the Carnegie-led team looked at that data as a function of observing time, instead of averaging it, they saw what the transient explosion of radiation really was: a stellar flare. The detection of the flare reduces the evidence that there is a substantial amount of dust around Proxima Centauri or that the star has a rich planetary system.



This graph shows the brightness of the star Proxima Centauri as observed by ALMA over two minutes of the event in March 2017. The massive flare is shown in red, with the smaller earlier flare in orange, and the enhanced emission surrounding the flare that could mimic a disk in blue. At its peak, the flare increased the star's brightness by 1,000 times. The shaded area represents uncertainty.

Image courtesy Meredith MacGregor

Genetics/Developmental Biology

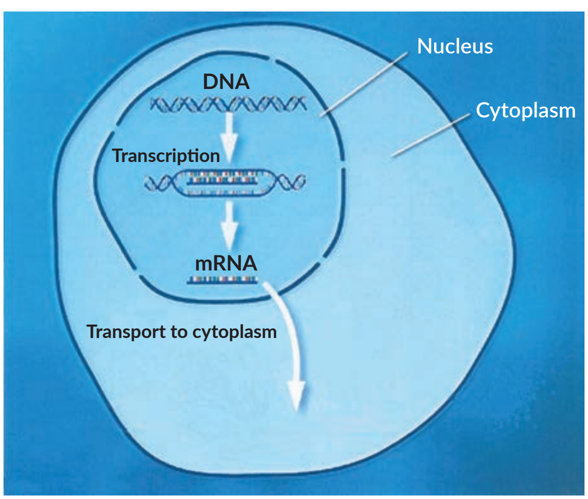
Deciphering the Complexity of Cellular, Developmental, and Genetic Biology

"Surprisingly, they found that egg cells lacking *FMR1* were initially normal, but with storage they lost function . . ."

Autism Linked to Problems Creating Large Proteins

New work from Carnegie's Ethan Greenblatt and Allan Spradling reveals that genetic factors underlying the most common cause of autism, fragile X syndrome, and potentially other related disorders stem from defects in the cell's ability to create unusually large proteins.

Their work investigates the *FMR1* gene. Mutations of it create problems in the brain and reproductive system, leading to fragile X syndrome and premature ovarian failure.



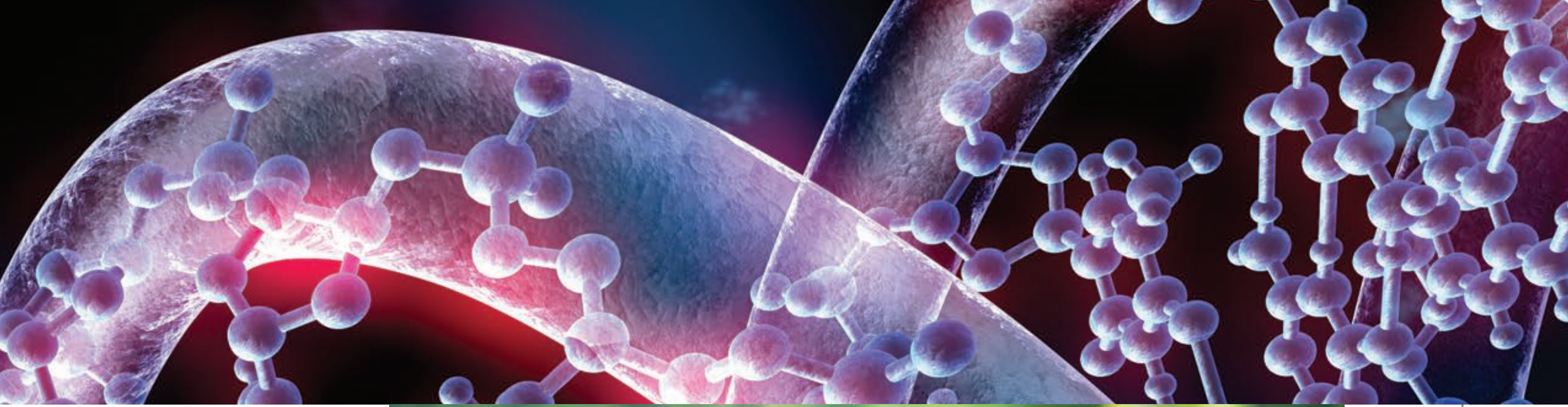
Transcription is the first step of turning a gene on to make a protein. It occurs in the cell nucleus (left) where a segment of DNA is copied into a complementary bit of RNA, which carries code from the nucleus to a protein-manufacturing site. The RNA's code is then translated into a protein.
Image courtesy U.S. National Library of Medicine (adapted)

It was already thought that *FMR1* is essential to the last stages of the gene's protein-making process. Genetic information in DNA molecules is tightly bound in cell nuclei. Before the cell can read a protein instruction, it is copied, or transcribed, by RNA, which carries code bits from the nucleus to a protein-manufacturing site. The RNA's code is then translated into a string of amino acids.

Usually these steps are rapid. However, in cells such as neurons and eggs, RNA is created and stored for future use.

Previous work suggested that *FMR1* prevents the stored RNA molecules from overproducing new proteins. Since many of these studies were done with brain cells, Greenblatt and Spradling investigated *FMR1's* effects on the protein-manufacturing process in the simpler fruit fly egg cell.

Surprisingly, they found that *FMR1* did not act to prevent protein overproduction, but functioned to prevent the underproduction of several hundred proteins some of which cause autism if reduced



The new research from Carnegie's Ethan Greenblatt (right) and Allan Spradling (left) reveals that genetic factors underlying the most common cause of autism, fragile X syndrome, and potentially other related disorders result from defects in the cell's ability to create unusually large proteins.

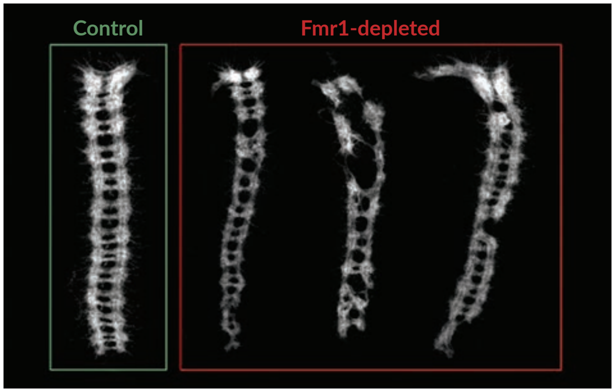
Image courtesy Jeremy Hayes

by even 50%. Most of these proteins shared the common feature that they are much larger than average.

Reducing *FMR1* in eggs also caused problems when the eggs were fertilized and started to develop into offspring. Many of the eggs failed to develop successfully if they had been stored in the ovary, which is reminiscent of the human ovarian failure syndrome. Other fertilized *FMR1*-lacking eggs created offspring with nervous system defects reminiscent of fragile X syndrome.

The researchers believe that *FMR1* boosts the production of critical large proteins that are difficult for eggs or neurons to manufacture. Without *FMR1*, egg cells have too little of these proteins and go bad prematurely during storage. Since *FMR1* also functions in the brain, the loss of large proteins in the brains of fragile X syndrome patients could explain their autism symptoms.

Future research could focus on large protein manufacturing and its link to aging or disorders, such as Alzheimer's and ALS.



This image shows an example of defects in the development of the embryonic central nervous system in stored eggs that lacked the *FMR1* gene. Unstored eggs showed normal development. Similar to the spinal cord, the image on the left is a normal ventral nerve cord with functioning *FMR1*. The ladder-like ventral nerve cords on the right are from stored eggs lacking *FMR1*.

Image courtesy Ethan Greenblatt

Genetics/Developmental Biology

Continued

Hijacking Jumping Genes Cause Disease, Drive Evolution

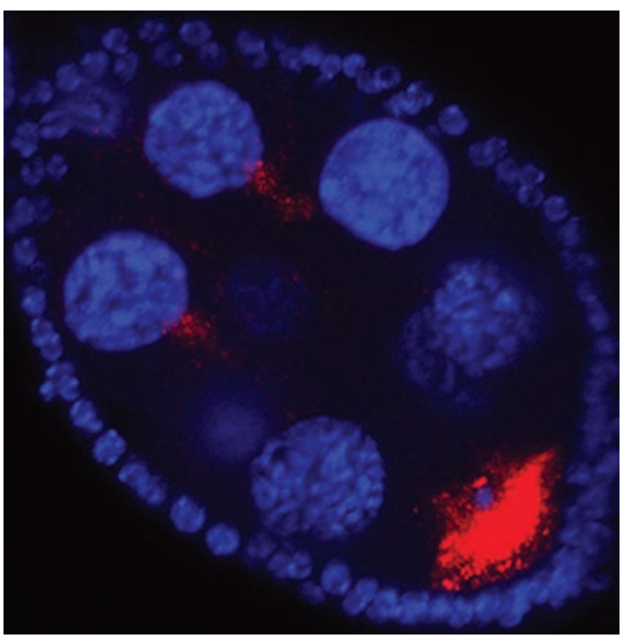
Almost half of our DNA sequences are made up of jumping genes called transposons. They jump around the genome in developing sperm and egg cells and are important to evolution. But their movement can also cause mutations that lead to diseases, such as hemophilia and cancer. Since Carnegie's Nobel Laureate Barbara McClintock discovered jumping genes more than six decades ago, scientists have not understood how they mobilize and prepare for their next generation, until now.

The Carnegie team, led by Zhao Zhang with Lu Wang, Kun Dou, Sungjin Moon, and Frederick Tan, developed new techniques to track jumping gene movement. They found that during a particular period of egg development, a group of jumping genes called retrotransposons hijacks special cells called nurse cells that nurture the developing eggs. The jumping genes use nurse cells to produce invasive material, copies of themselves called virus-like particles, that moves into a nearby egg and then into the egg's DNA.

> "The jumping genes use nurse cells to produce invasive material . . . that moves into a nearby egg and then into the egg's DNA."

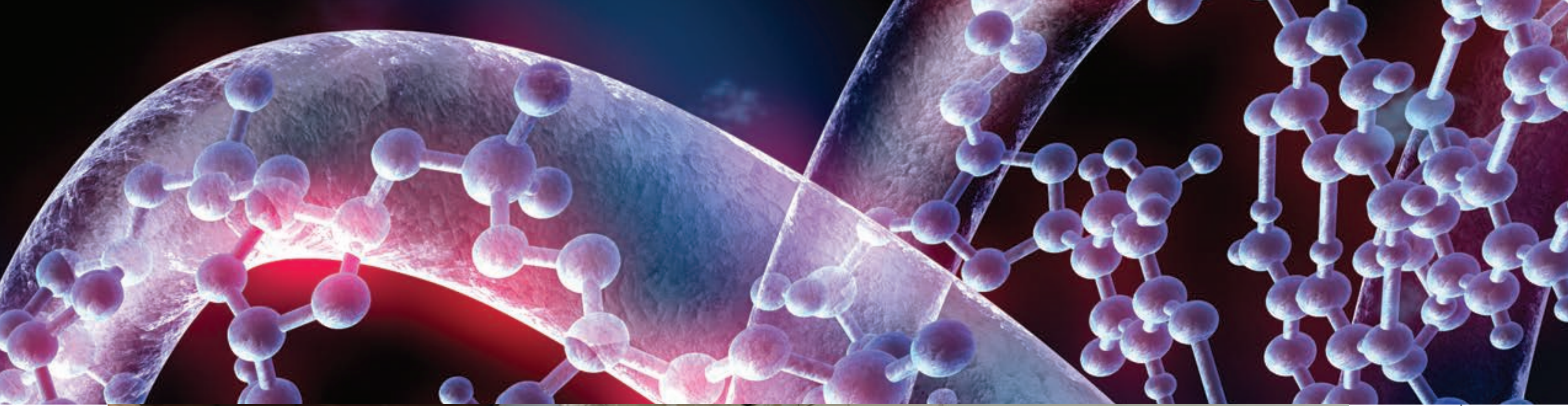
Animals developed a powerful system to suppress jumping gene activity that uses small, noncoding RNAs called piRNAs which recognize and suppress jumping gene activity. Occasionally, jumping genes still manage to move, suggesting that they employ special tactics to escape piRNA control. Tracking the movement of jumping genes to understand their tactics has been daunting.

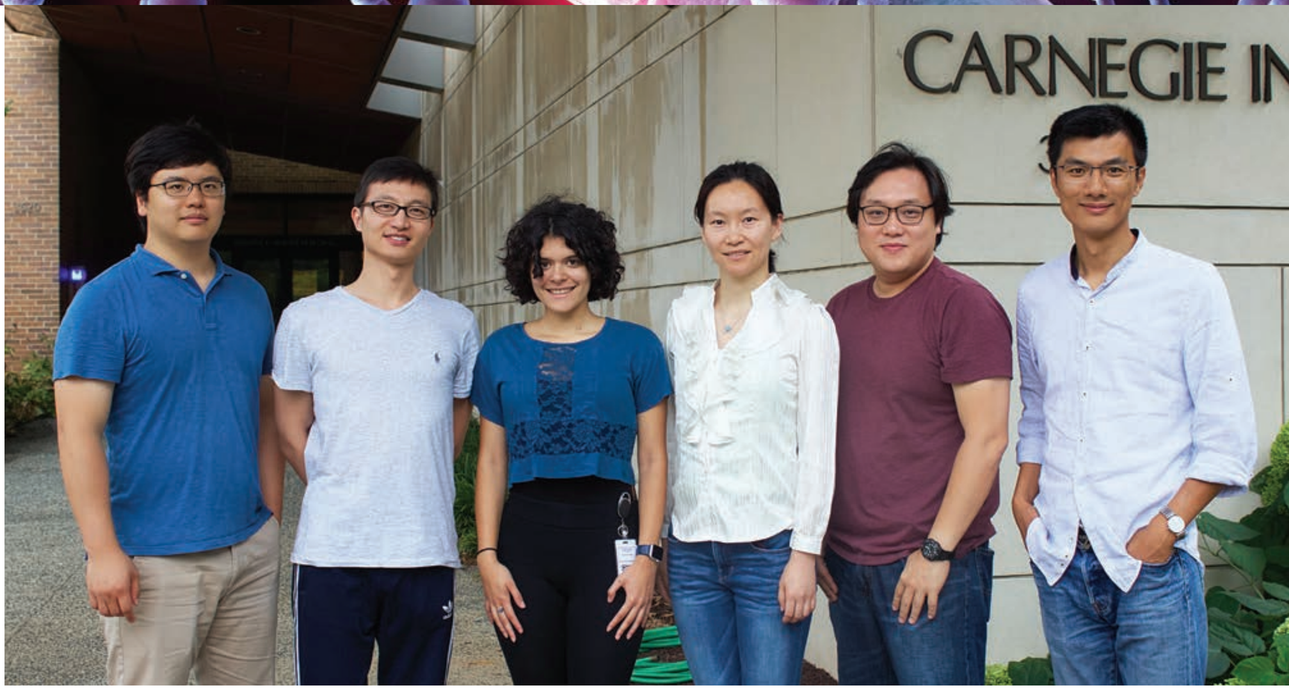
The Carnegie team tracked jumping gene movements using the fruit fly *Drosophila melanogaster*. They disrupted piRNA suppression to increase the activity of the jumping genes, then monitored their movement during egg development, which led to their discovery on the tactic that allows jumping genes to move.



The blue spheres in this image are nurse cells. The red is the developing egg lighting up from the invading material from the jumping genes.

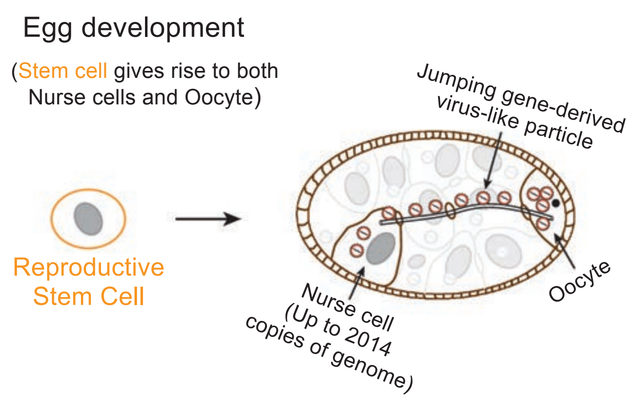
Image courtesy Zhao Zhang





Team members on the jumping gene research (from left to right): Leon Lin, Lu Wang, Victoria Bonefont, Kun Dou, Sungjin Moon, and Zhao Zhang.
Image courtesy Zhao Zhang

Surprisingly, jumping genes barely moved in stem cells that produce developing egg cells, possibly because the stem cells would only have two copies of the genome for these jumping genes to use. Instead, the moving genes used the nurse cells, which could provide thousands of copies of the genome per cell. The nurse cells were used like factories to manufacture the virus-like particles capable of integration. Rather than integrating into nurse cells, they waited to be transported into an interconnected egg cell, then added hundreds or more copies of themselves into the egg DNA. These parasitic genetic elements timed their activity and distinguished between different cell types to drive evolutionary change and cause disease.



Jumping genes, which mobilize around the genome, use nurse cells to manufacture invading products that preferentially integrate into the genome of developing egg cells called oocytes.
Image courtesy Zhao Zhang

Global Ecology

Linking Ecosystem Processes with Large-Scale Impacts

"... the ocean-based farms could generate at least three times more power ..."

Wind Wranglers on Land and Sea

Wrangling the wind to extract the most power from turbines is no simple task. Clara Garcia-Sanchez and Anna Possner, two postdoctoral fellows in Ken Caldeira's lab, use sophisticated, theoretical models to understand the geophysical opportunities and limits to wind power extraction on land and at sea to sustainably power humanity.

Ideally, more wind energy could be extracted if turbines formed one long row facing a steady wind. But due to numerous constraints, turbines are arranged in rows. This lowers the wind-energy harvest due to the "wake effect." Once wind energy is extracted from a turbine, the downstream wind has reduced energy, forming a wake. Turbine turbulence and downward mixing of momentum are further complications.

Focusing on the wake, Garcia-Sanchez is analyzing the effects wind farms have on land winds. She

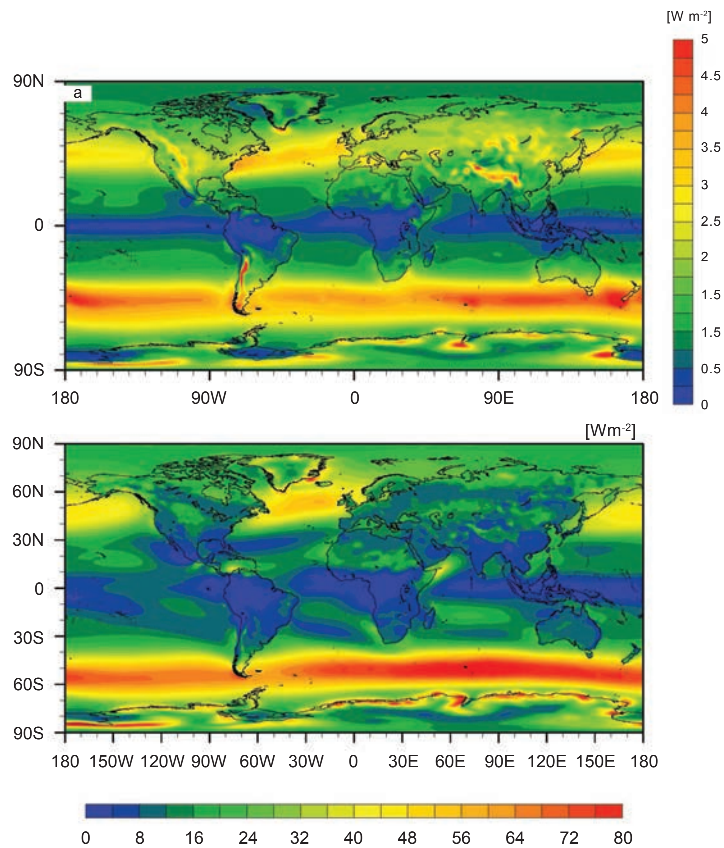
Clara Garcia-Sanchez (left) and Anna Possner (right) are looking at a computer simulation where blue and surrounding areas within the white contours show depressed wind speeds in and around a land wind farm that is 50 miles x 50 miles (81 kilometers x 81 kilometers).

Image courtesy Ken Caldeira

examines different wind farm sizes over North America, looking at the wake caused by the whole wind farm, to answer questions such as what happens to the wake length if wind farm size increases, or how power extraction changes when a farm is in the wake of another farm. Answers to these questions can help determine the optimal separation between farms for greater energy.

Possner looked at the dynamics of ocean-based wind farms and whether they could outperform land farms. Since wind speeds are higher on average over the ocean, ocean farms could theoretically intercept more energy. She investigated whether the open-ocean winds are faster because there is nothing to slow them down and whether these farms would slow the winds similarly to land farms.

Possner modeled the productivity of large Kansas wind farms compared to theoretical open-ocean wind farms and found that the ocean-based farms could generate at least three times more power, particularly in the North Atlantic. Drag from turbines would not slow ocean winds as much due to the faster downward transport of momentum sustained by the land-sea contrast in surface temperature. This tremendous ocean wind power is very seasonal, however. In the winter North Atlantic wind farms could theoretically provide sufficient energy to meet all of civilization's current needs. In the summer they could generate enough power for Europe, or the United States alone.



Anna Possner's wind power extraction study was a hypothetical, to get a sense of where in the world's oceans the wind and circulation patterns could sustain the highest rates of energy extraction near the surface. As a first step, the researchers modeled turbines placed all over the globe, on land and sea, at a density of one turbine per square kilometer. They ran simulations that included the interaction of turbines, which substantially slows the winds and limited extraction to less than 5 watts per square meter (5 W/m^2) (top). If turbine density did not slow down the winds, they could achieve extraction rates of up to 80 watts per square meter (80 W/m^2) (bottom). Note the different contour scales for each panel.

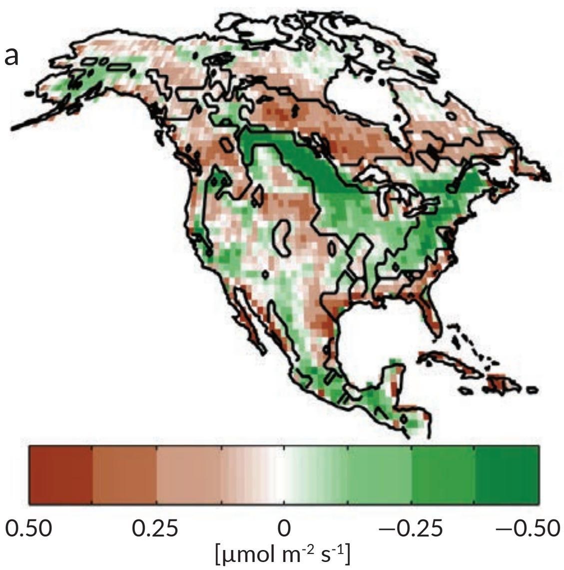
Image courtesy Anna Possner

Global Ecology

Continued

New Way to Assess Carbon Uptake Patterns

Yoichi Shiga, Anna Michalak, Joe Berry, and colleagues used a dense network of atmospheric carbon dioxide (CO_2) observations to provide, for the first time, a regional scale evaluation of a new satellite-based measurement called solar-induced chlorophyll fluorescence (SIF). SIF is a photosynthetic by-product, which occurs as sunlight excites chlorophyll during photosynthesis. SIF offers the potential to track photosynthesis from space with unprecedented resolution and coverage. To date, analysis of SIF had been limited to either plot (~1 square kilometer) or global/hemispheric scales. Regional to continental scales critical for policy decisions and informing carbon-climate feedbacks remained unexplored, until now.



> "...SIF outperforms existing vegetation indicators and a majority of sophisticated terrestrial biosphere models in tracking net CO_2 exchange..."

Using three years of data from the dense North American network of atmospheric CO_2 observation towers, the researchers found that SIF outperforms existing vegetation indicators and a majority of sophisticated terrestrial biosphere models in tracking net CO_2 exchange by exhibiting regional patterns more consistent with the atmospheric data.

They used an atmospheric transport model to relate the patterns of different surface variables to the fluctuations observed in the atmospheric CO_2 data. To identify the impact of SIF on carbon flux patterns, they compared two sets of inverse-modeling estimates of carbon uptake, one with SIF and one without SIF.

A new satellite-based measurement called solar-induced chlorophyll fluorescence (SIF) measures a photosynthetic by-product, which occurs as sunlight excites chlorophyll during photosynthesis. When SIF information is included in observations, there is a redistribution of the growing season carbon dioxide uptake from needleleaf forests to croplands, with green indicating a stronger net carbon uptake and brown a weaker net carbon uptake. The difference between June, July, and August flux estimates are obtained from inverse models with and without SIF, averaged over three years (2008-2010). Inverse modeling starts with the results and then calculates the causes.

Image courtesy Yoichi Shiga

Carnegie's Yoichi Shiga (left), Anna Michalak, Joe Berry (right), and colleagues conducted a study showing new carbon dioxide uptake patterns.
Image courtesy Yoichi Shiga

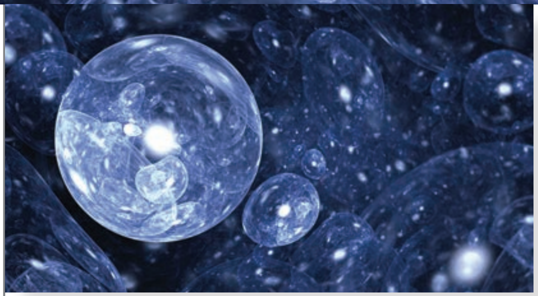
Inverse modeling starts with the results (atmospheric CO_2 variations) and then calculates the causes (CO_2 fluxes at the Earth's surface).

They also found that SIF indicates a redistribution of the North American land carbon sinks with increased CO_2 uptake in croplands and decreased CO_2 uptake in needleleaf forests during the growing season.

These results are the first instance of using a network of CO_2 observations to evaluate the utility of SIF in understanding space and time variability of carbon uptake at crucial regional to continental scales. Furthermore, these results offer a new, powerful tool to probe the photosynthetic activity of plants and how plants affect the atmosphere.

Matter at Extreme States

Probing Planetary Interiors, Origins, and Extreme States of Matter



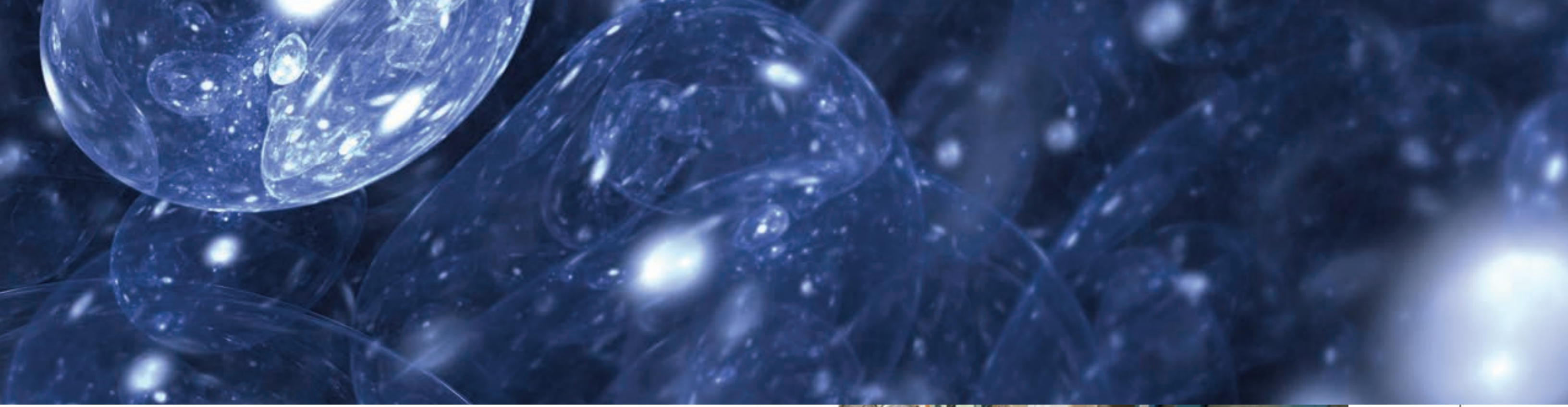
Simple Glasses, Not So Simple Science

Of all the elements, hydrogen in the form of water has the most profound control of matter and energy flow in the deep Earth. Understanding how water controls the melting of rock and migration of melt is essential to deciphering Earth's formation and evolution. Deep transport mechanisms within terrestrial planets are governed by physical and chemical properties of silicate melts called magma, which in turn are strongly controlled by water-silicate interactions. Experiments by George Cody and Bjørn Mysen, with postdoctoral fellows and interns, have revealed that water-melt interactions are more complex than previously thought.

Cody uses nuclear magnetic resonance (NMR) spectroscopy to determine the fine-scale molecular structure of certain isotopes common in glasses formed from rapidly cooled silicate melts. Isotopes are variations of an element with the same number of protons but a different number of neutrons. By focusing on "simple" melt compositions, Cody, Mysen, and their team sought to reveal the fundamental physical chemistry of melt-water interactions. Certain isotopes, including hydrogen (^{1}H), hydrogen with two neutrons called deuterium (^{2}H), oxygen (^{17}O), aluminum (^{27}AL), and silicon (^{29}Si), have a fundamental quantum property called spin that can be detected by NMR. With NMR it is possible to investigate each isotope without any interference from others, providing the clearest possible molecular picture of solids like glasses.

George Cody is checking cable connections prior to conducting a solid-state nuclear magnetic resonance (NMR) experiment at the W.M. Keck Solid State NMR facility. The large silver cylinder is the superconducting solenoid magnet providing a static magnetic field that is about 150,000 times stronger than Earth's magnetic field. The cabling on the floor directs the flow of radio frequency pulses to the sample being studied, which sits at the center of the magnetic field. The solid-state NMR allows scientists to explore the chemistry of solid materials exploiting a physical property of matter known as intrinsic spin present in a wide range of stable isotopes, related elements with the same number of protons but different numbers of neutrons. Funding for the NMR laboratory was provided the W.M. Keck Foundation, the National Science Foundation, and the Carnegie Institution for Science.

Image courtesy George Cody



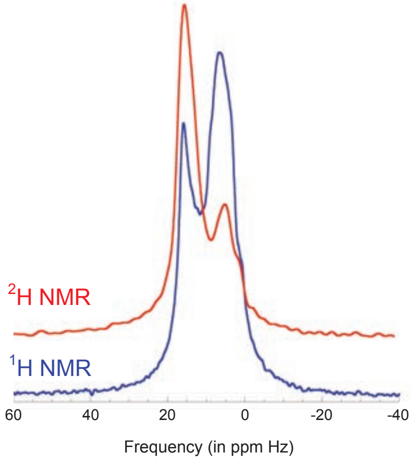
"A particularly surprising discovery was that the two isotopes of hydrogen behaved very differently in the melt structure."

Typically, water in silicate melts is thought to either dissolve in the melt as water or react with the melt, converting the silicon bond Si-O-Si to silanol, Si-OH. For decades it has been understood that water-melt reactions depend on the amount of water. Variations in the chemistry of the melt were thought to have minimal effect. Focusing on ^1H and ^2H, Cody and colleagues showed that melt chemistry actually has a very strong control on what water does.

A particularly surprising discovery was that the two isotopes of hydrogen behaved very differently in the melt structure. One of the great mysteries of Earth's chemistry is why the ratio of deuterium to hydrogen of Earth's water is significantly larger than that of the Sun and the universe. Earth's oceans evolved from a primitive magma ocean, and the fact that the hydrogens behave so differently in the melt structure could help explain why Earth's oceans have the deuterium to hydrogen ratio that is observed today.

Carolyn Beaumont, a summer research intern working with staff scientists George Cody and Bjørn Mysen, prepares alkali silicate oxide–water samples for melting under high pressures and temperatures. Critical to these studies is the ability to seal the starting materials in platinum reactors. Beaumont is using a microscope and a pulsed DC arc welder to make high-precision micro-welds that will ultimately seal and retain water in the silicate melts when heated to temperatures as high as 2550°F (1400°C) and pressures of 15,000 times normal atmospheric pressure using a piston-cylinder solid medium pressure device.

Image courtesy George Cody



This graphic shows the difference of heavy hydrogen called deuterium (^2H or D) and regular hydrogen (^1H) in hydrated silicate glasses that were quickly cooled from melts. From a chemical perspective, D_2O and H_2O are expected to behave very similarly; however, nuclear magnetic resonance (NMR) results clearly show that deuterium (red) and hydrogen (blue) have strong preference for different molecular environments in the amorphous glass. Classical isotopic fractionation theory, which explains separation processes, cannot explain this significant preference. This high degree of preference may have left a distinct isotopic signature, recording the process when liquid rock and water separated, leading to the condensation of Earth's oceans during the earliest history of the planet.

Image courtesy George Cody

Matter at Extreme States

Continued

Distorted Structure Could Advance Electronics

Viktor Struzkhin, Jianjun Ying, and team found unusual structural changes in the semiconductor tin diselenide, $SnSe_2$, when it was subjected to pressure. Electrical conductivity can be turned on and off in semiconductors, a powerful property for electronics. Tin diselenide is a very thin, one-atom layered semiconductor, with a regular, repeating crystalline arrangement of atoms. It is called a transition metal dichalcogenide (TMD) and can be used to create smaller, cheaper transistors, solar cells, LEDs, photodetectors, and more. The researchers' observations contrast with findings in other metallic TMDs, so the newly created structure may provide novel research opportunities for these promising materials.

The team subjected tin diselenide to pressures exceeding 170,000 times atmospheric pressure (17 gigapascals). They performed X-ray diffraction to see structural changes, Raman spectroscopy to observe vibrational changes, and electronic transport measurements. They combined their observations with theoretical calculations on the material's behavior.

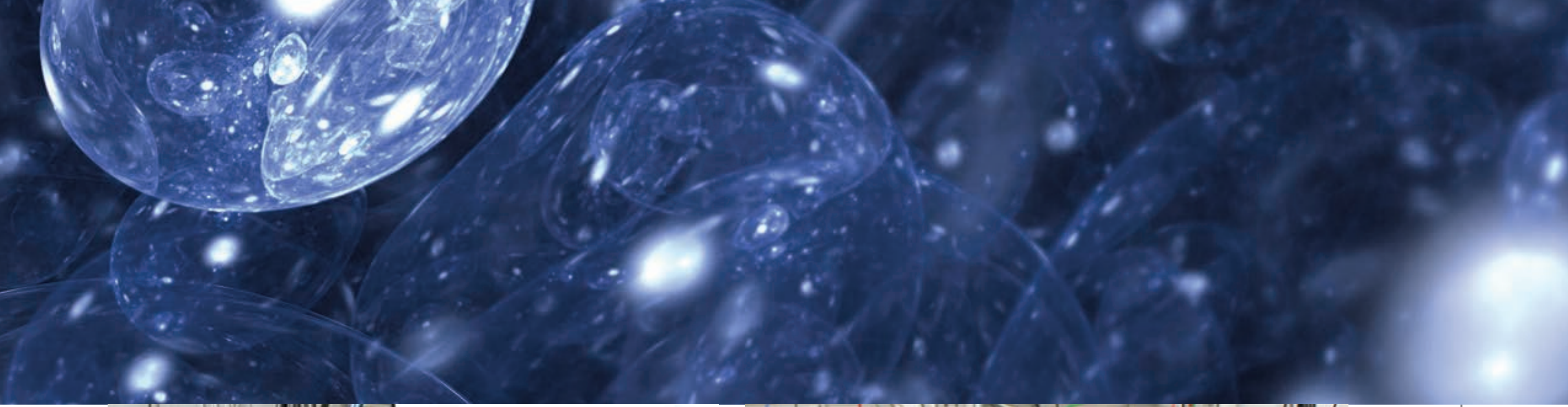
"... the newly created structure could provide novel research opportunities for these promising materials."

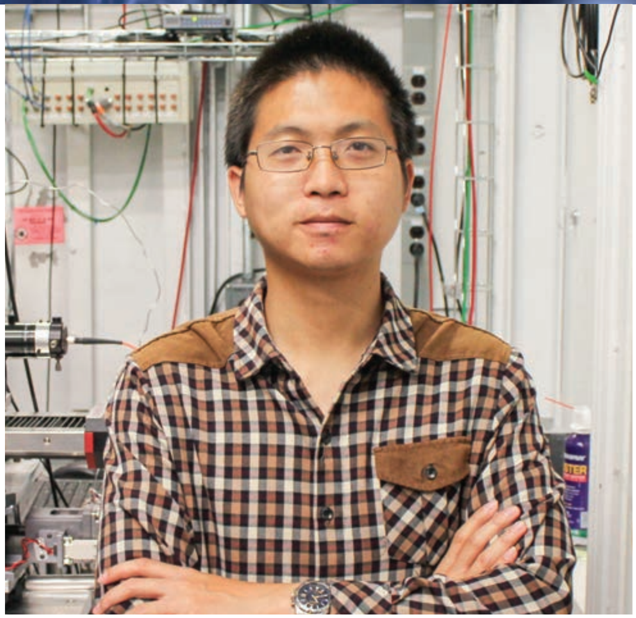
At pressures above 170,000 atmospheres they found periodic distortions to the lattice structure that were related to the so-called charge density wave. This wave is an ordered quantum fluid of electrons that forms a wave pattern and can carry an electric current similar to the superconducting state wherein there is no resistance to electron flow. But unlike a superconductor, the electric charge density wave current can be interrupted or distorted making a superlattice of atoms, which can be useful for many applications.

The theoretical work suggests the charge density waves occur from a special arrangement of electronic states called Fermi nesting conditions. These conditions occur in the "momentum space" of electrons, a different kind of space than we are used

At left, the electron density (below the red line) is uniform. At right, when the researchers applied pressure, the regular, repeating arrangement was changed, forming a charge density wave with gaps between atoms in the distorted arrangement.

Image courtesy Viktor Struzhkin

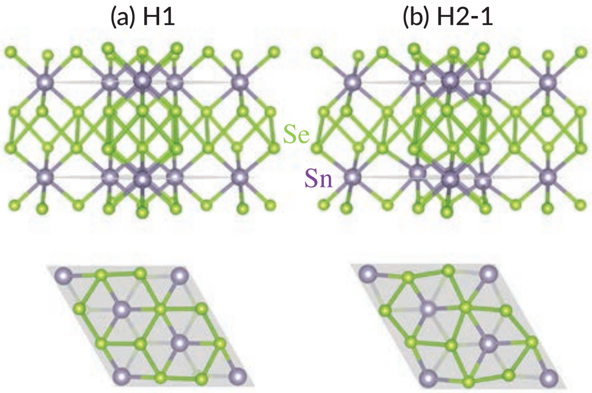




Viktor Struzkhin (left), Jianjun Ying (right), and team discovered the unusual structural changes in the semiconductor tin diselenide, $SnSe_2$, when it was subjected to pressure.

Images courtesy Viktor Struzhkin

to, where electrons are located on a so-called Fermi surface. Fermi surfaces with nearly flat parts parallel to each other are described as the nesting condition. Typically, high pressure would suppress the nesting condition, destroying the distorted lattice structure and its charge density wave. But that did not happen. Instead, the researchers found that the Fermi nesting condition and strong electron-vibrational coupling occur under pressure with the same momentum and wave direction. This result agreed with their theoretical calculations, but differed from findings in similar materials where the Fermi nesting was found to be less significant in creating the charge density wave state. This surprising finding opens new opportunities for these materials.



This illustration compares the parent, undistorted structure (a) of the semiconductor tin diselenide, $SnSe_2$, to an out-of-plane displacement of the Sn atoms (grey) in the distorted structure (b). The distortion resulted in a slight buckling of the Sn layers and a shift of the Se atoms (green), distorting the top-view (two images at bottom) hexagonal symmetry.

Image courtesy Elena Margine

Plant Science

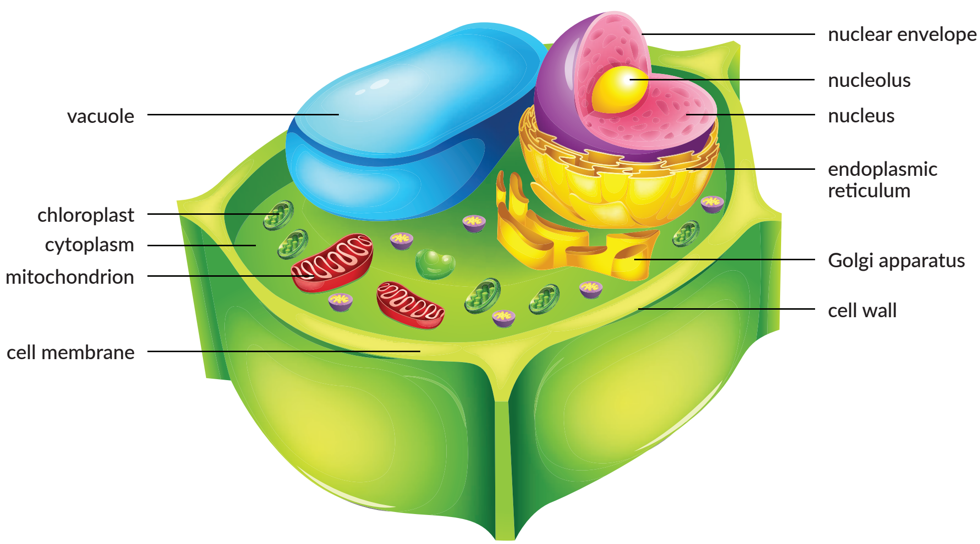
Characterizing the Genes of Plant Growth and Development

> "Such findings could be important to controlling crop yields under different environmental conditions."

Pivotal Protein to Photosynthesis Found

Photosynthesis is a process by which plants, algae, and some bacteria use solar energy to convert water and carbon dioxide into food, coupled with oxygen release. It is vital for nearly all life on Earth. Arthur Grossman, graduate student Tyler Wittkopp, and team found that a previously uncharacterized protein plays a critical role in photosynthetic function, the accumulation of an essential photosynthetic electron transport complex, and survival of cells exposed to high light. Such findings could be important to controlling crop yields under different environmental conditions.

Some years ago, Grossman and colleagues, using computational methods, identified a suite of proteins called the GreenCut. These proteins are present in all plants and green algae but not in nonphotosynthetic organisms. About half of these proteins had no known biological function, although many were localized to the cellular organelle called the chloroplast, where photosynthesis takes place. Since then, a variety of GreenCut proteins have been found to function within chloroplasts in processes



Plants, algae, and some bacteria use the Sun's energy to convert water and carbon dioxide into food and release oxygen. Organelles called chloroplasts, shown in this plant-cell artwork, are where this activity takes place. Grossman and team identified a critical protein essential to this process.

Illustration blueringmedia © 123RF.COM

Stanford graduate student Tyler Wittkopp (left) was lead author on the study, working with Carnegie's Arthur Grossman (right) and other team members.
Image courtesy Tyler Wittkopp

ranging from assembling photosynthetic complexes to influencing electron transport and carbon fixation.

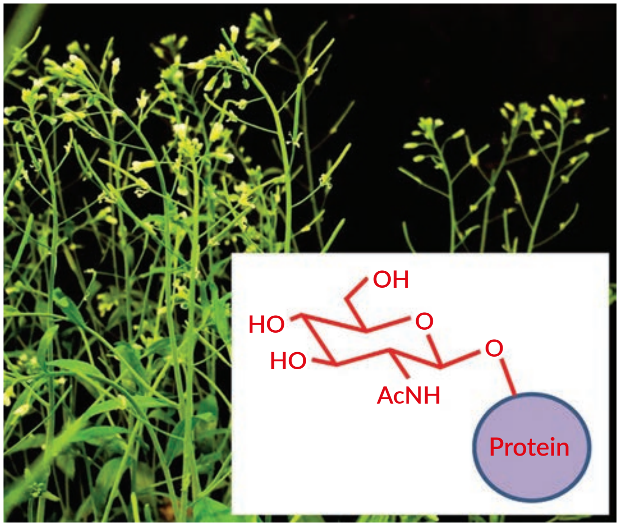
The photosynthetic apparatus is made up of pigment-protein complexes within specialized chloroplast membranes called thylakoids. The major complexes involved in the conversion of solar energy (i.e., light) to chemical energy (i.e., sugars) include light-capturing photosystems and the cytochrome b_6f complex.

Photosynthetic electron transport is highly regulated and must be coordinated with cellular and environmental cues. Using the green alga *Chlamydomonas reinhardtii*, the team discovered that a GreenCut protein called CPLD49 was critical for maintaining normal photosynthesis. A *Chlamydomonas* strain devoid of CPLD49 was unable to grow without a fixed carbon source when exposed to high light, suggesting an important role for CPLD49 under such conditions.

Grossman and colleagues also showed that CPLD49 plays a critical role in photosynthetic electron transport and is necessary for the accumulation of the cytochrome b_6f complex; *Chlamydomonas* lacking CPLD49 showed a nearly 90% loss of this complex. Interestingly, CPLD49 appears to interact with another GreenCut protein, CPLD38, which is also critical for cytochrome b_6f accumulation. How these GreenCut proteins affect the cytochrome b_6f complex is unknown, but they may be involved in making a cofactor associated with the complex or altering the nature of the membrane environment. These and other discoveries may provide unique opportunities for engineering photosynthesis to function over a range of environmental conditions.

The Long Reach of Sugar-Tagged Proteins

Photosynthesis converts carbon dioxide into sugar, the source of energy for all life. The amount of sugar available in the body or cell must be monitored to control normal metabolism and growth in animals and plants. One of these control mechanisms is to modify proteins with sugar molecules, such as O-linked acetylglucosamine (O-GlcNAc). Protein O-GlcNAc modification is very important to a range of cellular, physiological, and disease processes in mammals. Altered levels of this modification have been associated with diabetes, cardiovascular disease, and cancer. However, until now its role in plants has remained elusive.



The team studies O-GlcNAc modifications in the model plant *Arabidopsis* (background). The inset shows how a sugar molecule is attached to the protein when it undergoes the O-GlcNAcylation modification process.

Image courtesy Shouling Xu

> " . . . until now its role in plants has remained elusive. . . "

Carnegie researchers Shouling Xu, Dasha Savage, and Zhiyong Wang with colleagues have for the first time identified 262 proteins and their sites that are modified by O-GlcNAc in a plant. Many of these proteins are known to regulate important processes, such as gene activation, response to hormones, and the timing of flowering. This work lays the foundation for further understanding of the importance of O-GlcNAc modification to plant growth and crop productivity.

Genetic evidence shows that when two enzymes, SPINDLY and SECRET AGENT, that carry out this modification are inactivated, the plant embryo dies. But very few proteins modified by O-GlcNAc had been identified in plants.

The team conducted a large-scale proteomic analysis of the model plant *Arabidopsis thaliana*. (Proteomics is the large-scale study of proteins.) They extracted proteins from inflorescence tissue, broke the proteins into constituent peptides, and then enriched O-GlcNAc-modified peptides using a technique called lectin weak affinity chromatography. They then employed mass spectrometry to determine the sequence of the peptides and the amino acid

Carnegie's Shouling Xu was lead author of the study.
Image courtesy Shouling Xu

residues that are modified by O-GlcNAc. This yielded 971 modified peptides pointing to 262 O-GlcNAc-modified proteins.

The team found evidence that the subcellular localization and biochemical functions of many of the plant O-GlcNAc–modified proteins are similar to those in animals, supporting its importance as a basic mechanism of cellular regulation. The study also uncovered potentially plant specific functions of O-GlcNAcylation, prominently in modulating key components of several plant hormone pathways. This groundbreaking study opens up an area of exploration that will advance our understanding of how sugar level modulates plant growth and development, which is a key link from photosynthesis to biomass accumulation that could help increase crop yields.

2017-2018 YEAR BOOK

Friends, Honors & Transitions

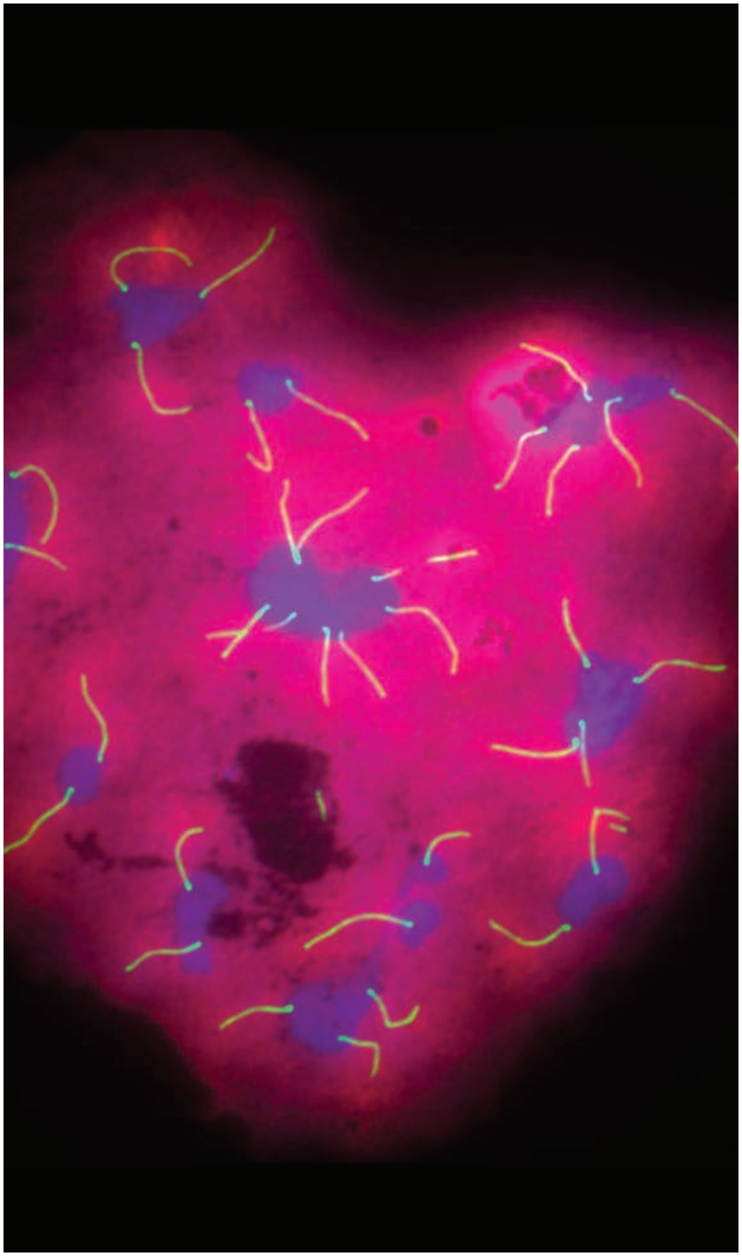
Image courtesy Greg Asner

Carnegie Friends

Philanthropy has been the heart of Carnegie Science since Andrew Carnegie made his first gift of $10 million, which established the institution in 1902. Many generous individuals and foundations have since demonstrated a commitment to scientific pursuits that create new frontiers, expand human understanding, and launch the next generation of discoveries. We celebrate your investment in Carnegie Science, which helps our investigators' ability to explore beyond the boundaries of space, Earth, and life sciences. You've empowered Carnegie scientists with the ability to take risks and chart new—often, previously unimagined—research paths. Together, we are exploring new vistas of knowledge, and we are proud and thankful that you are our partner in this scientific enterprise.

This year your generosity helped support postdoctoral fellowships, develop astronomical instrumentation, advance the Carnegie Venture Grant program, broaden coral research, and much more.

The following listings include those who have generously supported Carnegie Science, including individuals and those who have given from private foundations and donor-advised funds.



Fluorescent tags track molecular processes in this image from the Bortvin lab at the Department of Embryology.

Image courtesy Bortvin Laboratory

The Carnegie Founders Society

When Andrew Carnegie made his original $10 million gift, he did so with the audacious goal of establishing an independent research organization that would increase scientific knowledge for the improvement of humankind. Likewise, members of the Carnegie Founders Society are visionaries who—through their generosity and entrepreneurial spirit—lay the foundations for innovation, ingenuity, and intellectual courage to thrive. Through their lifetime contributions of $10 million or more, these individuals have empowered scientists to pursue the most profound challenges in modern science and truly transform our relationship to the universe and world around us.

Caryl P. Haskins*
William R. Hewlett*
George Mitchell *
* Deceased

THE CARNEGIE HABITABILITY PROJECT

The Carnegie Habitability Project will investigate which planetary features contribute to the habitability of a planet. The only planet that we know is habitable is Earth. But with over 3,000 exoplanets discovered in the galaxy so far, it is likely that there are others.

In making momentous gifts, members of the Carnegie Founders Society imagined providing resources for projects that would fundamentally alter our understanding of ourselves, our planet, and our universe—projects like the Carnegie Habitability Project.

We are standing at a critical moment in our knowledge of both the farthest reaches of the universe and Earth's life-sustaining history. As the field of exoplanet science explodes, in large part due to crucial discoveries from Carnegie scientists, researchers around the world are shifting their focus from identifying new exoplanets to determining which, like Earth, might support life.

With the support of Carnegie's philanthropic leaders, the Carnegie Habitability Project is poised to lead the field of exoplanet science towards determining which features contribute to the habitability of a planet. Investments of over $10 million in postdoctoral associates, advanced equipment, technologies, and materials will accelerate the incredible work Carnegie researchers have already launched. With the right in-house expertise, equipment, and technologies Carnegie scientists can move swiftly, as no other institution or university can, to open new frontiers in exoplanet and planetary habitability research.

> "This is the beginning of a new kind of science . . . "

This is the beginning of a new kind of science: one that harnesses the expertise of geologists, astronomers, physicists, chemists, experimentalists, and theorists to create a comprehensive understanding of planetary habitability. Moreover, it will provide the direction needed to chart the course to new planets and possibly life elsewhere in the universe, and that course begins with the scientific and philanthropic visionaries who are committed to forging the way.

The most famous astronomer of the 20th century, Carnegie's Edwin Hubble, is the namesake of the most famous space-based telescope so far, the Hubble Space Telescope shown in this illustration.
Image courtesy NASA/ESA

The Edwin Hubble Society

Science often requires years of hard work and dedication before major discoveries can be made, and Edwin Hubble Society members make the critical investments that allow our scientists to take calculated risks in pursuit of new knowledge. Carnegie scientist Edwin Hubble, the most famous astronomer of the 20th century, shattered our old concept of cosmology by observing that the universe is vastly larger than we thought and is, in fact, expanding. We are proud to honor the members of the Edwin Hubble Society, who have fostered such extended, paradigm-changing research through their lifetime contributions of $1,000,000 to $9,999,999.

Anonymous
D. Euan and Angelica Baird
William H. Gates III
William and Cynthia Gayden
Michael and Mary Gellert
Robert G. and Alexandra C. Goelet
William T. Golden*
Crawford H. Greenewalt*
David Greenewalt*
Margaretta Greenewalt*
Robert and Margaret Hazen
Margaret and Will Hearst
Richard E. Heckert*
Kazuo and Asako Inamori
Burton* and Deedee McMurtry
Jaylee and Gilbert Mead*
Cary Queen
Deborah Rose, Ph.D.
William J. Rutter
Thomas and Mary Urban
Sidney J. Weinberg, Jr.*

* Deceased

"I am delighted to honor the newest member of the Vannevar Bush Society, Jane Wilson."

Remarks by Carnegie President Eric Isaacs, November 15, 2018

Image courtesy 5th & Market Photography

Michael and Jane Wilson have been staunch supporters of the science education program BioEYES since 2014. BioEYES was cofounded by Carnegie's Department of Embryology scientist Steve Farber who uses the zebrafish to teach Baltimore area teachers and students about genetics, development, and much more by watching the young fish grow and develop. The program has been particularly important to Jane who remarked: "As a 'Once-Upon-a-Time' teacher of 10-to-12-year olds in the public school systems of California and Maryland, I wish I had access to the BioEYES program or something similar years ago in my classrooms. BioEYES stimulates curiosity, hones a student's abilities of observation, trains children to read in the scientific method, and engenders a love and respect for science that will last a lifetime."

The Vannevar Bush Society

Vannevar Bush, the renowned leader of American scientific research of his time, served as Carnegie's president from 1939 to 1955. Bush believed in the power of private organizations and the conviction that it is good for man to know. The Vannevar Bush Society recognizes those who have made lifetime contributions between $100,000 to $999,999.

Anonymous (5)~
Philip H. Abelson*
Bruce and Betty Alberts
Mary Anne Nyburg Baker and G. Leonard Baker, Jr.
Daniel Belin and Kate Ganz
Bradley F. Bennett*
Didier and Brigitte Berthelemot
David P. Brown~
Donald and Linda Brown
Richard Buynitzky*
A. James Clark*
Tom and Anne Cori
John Crawford~
H. Clark and Eleanora K. Dalton*
John Diebold*
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Michael A. Duffy
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Jo Ann Eder
Bruce W. Ferguson and Heather R. Sandiford
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Martin and Jacqueline Gellert
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Diane Greene and Mendel Rosenblum
Gary K. Hart and Cary S. Hart
Henrietta W. Hollaender*
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Gerald D. and Doris* Laubach
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J. Irwin Miller*
Al and Honey Nashman
Evelyn Stefansson Nef*
Alexander Pogo*
Elizabeth M. Ramsey*
Vera and Robert Rubin*
Allan R. Sandage*
Leonard Searle*
Allan Spradling
Frank N. Stanton*
Christopher and Margaret Stone
Dawn Taylor~
David and Catherine Thompson
William* and Nancy Turner
Marshall Wais
C. Jane Wilson~
Michael G. Wilson
Laure Woods

* Deceased
~ New Member(s)

“I like to support education, physics, astronomy, and engineering . . . ”

Carnegie’s Las Campanas Observatory (LCO) is like a home-away-from-home for Second Century Legacy Society member John Thomas. He made his first trip to Chile after his daughter Joanna and son-in-law David Osip moved there in 2003, when David began working at LCO. David is now associate director. Captivated by its “magical” and “inviting” atmosphere, John has migrated south for the winter nearly a dozen times, visiting family and catching unparalleled glimpses of the Milky Way.

John began supporting the Observatories in 2005 with individual gifts that were matched by his former employer. “I wanted to support Dave and Joanna’s work, and get invited back,” he joked.

When John received some family money in 2009, it seemed only logical to set up an irrevocable trust to further his philanthropic goals. “I like to support education, physics, astronomy, and engineering, and I have a particular affection for Caltech and Carnegie.” With his irrevocable trust, John establishes a legacy that benefits his favorite institutions and himself.

John Thomas (middle) visits with daughter Joanna (right) and son-in-law David Osip (left) in Chile, in 2005. David Osip is currently the associate director of Carnegie’s Las Campanas Observatory in Chile.
Image courtesy David Osip

The Second Century Legacy Society

The Second Century Legacy Society recognizes individuals who make special commitments to Carnegie Science in support of scientific research and discovery through their wills, living trusts, estate plans, and other forms of planned giving. Members of this society carry on the vital tradition of philanthropy upon which Carnegie Science was founded, ensuring that throughout Carnegie’s next 100 years we have the resources to broaden scientific knowledge and cultivate future generations of leading scientists. Through their planned gifts, members meet their charitable and financial goals while creating legacies that support the research areas most important to them. We gratefully acknowledge these dedicated supporters, whose impact will be felt in tomorrow’s research advances.

Anonymous (3)
Philip H. Abelson*
Paul A. Armond, Jr.
Liselotte Beach*
Bradley F. Bennett*
Francis R. Boyd, Jr.*
Lore E. Brown
Gordon Burley
Richard Buynitzky*
Eleanor Gish Crow*
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Hugh H. Darby*
Herbert A. Dropkin
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William T. Golden*
Crawford H. Greenewalt*
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Gary K. Hart and Cary S. Hart
Caryl P. Haskins*
Robert and Margaret Hazen
Richard E. Heckert*
Henrietta W. Hollaender*
Paul A. Johnson*
Paul and Carolyn Kokulis
Nancy Lee
Gilbert and Karen Levin
Chester B.* and Barbara C. Martin
Al and Honey Nashman
Charles J. and Virginia E. Peterson~
Alexander Pogo*
Elizabeth M. Ramsey*
Holly M. Ruess
Allan R. Sandage*
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Maxine and Daniel Singer
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Fay M. Stetzer*
Thomas H. B. Symons, C.C.
John R. Thomas, Ph.D.
Ian Thompson~
Hatim A. Tyabji
William M. White
Robert and Roberta Young

* Deceased
~ New Member(s)

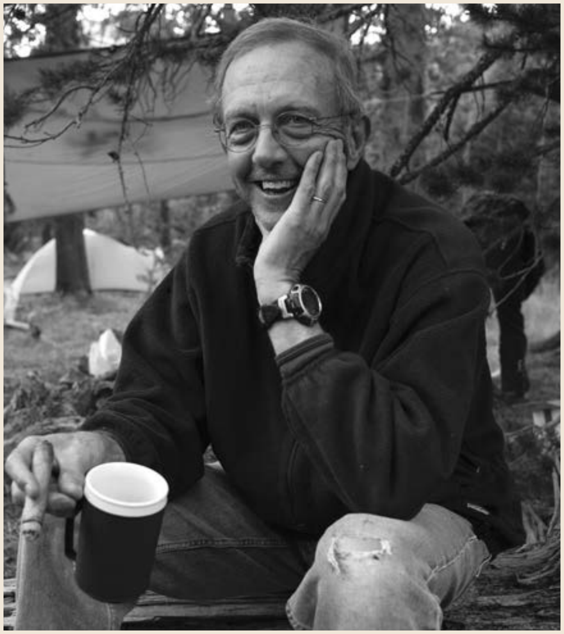
The Barbara McClintock Society

Annual contributions from generous individuals allow Carnegie Science's leadership to direct funds towards the most urgent needs and most promising research paths. They provide resources so that we can support investigators living at the forefront of bold scientific pursuits, such as Carnegie investigator Barbara McClintock, who won the Nobel Prize in Physiology/Medicine in 1983 for her work on patterns of genetic inheritance. We are thankful for these wonderful annual supporters, whose contributions are essential to sustain explorers like McClintock. With the McClintock Society, we recognize the generosity of donors who contribute $10,000 or more in a fiscal year.

$100,000 to $999,999
Anonymous (2)
Mary Anne Nyburg Baker and G. Leonard Baker, Jr.
Michael A. Duffy
Karen Fries and Richard Tait
Robert and Margaret Hazen
Al and Honey Nashman
Dawn Taylor
David and Catherine Thompson

$10,000 to $99,999
Anonymous (2)
Craig and Barbara Barrett
David P. Brown
Richard and Ann Chiu
John Crawford
John P. de Neufville
Sally De Witt
Stephen and Janelle Fodor
Martin and Jacqueline Gellert
Michael and Mary Gellert
Robert G. and Alexandra C. Goelet
Diane Greene and Mendel Rosenblum
Simon and Charlotte Harrison
Mary-Claire King
Douglas E. Koshland
David B. and Jan E. LeRoux
Michael T. Long
Christopher and Lois Madison
Michael McCormick and Christine McCarthy
Robert and Bethany Millard
Charles J. and Virginia E. Peterson
Deborah Rose, Ph.D.
Ray and Meredith Rothrock
Laura and Carlton Seaver
Christopher and Margaret Stone
Marshall Wais
Matthew Weitzman
Michael G. & C. Jane Wilson

"I had never had a year like that in my life before or since."



Carnegie Geophysical Laboratory alumnus John de Neufville

Image courtesy Phillip Periman

Former Carnegie predoctoral researcher John de Neufville has had a long and distinguished career building highly successful businesses in materials science. But it was his year at the Geophysical Laboratory in 1961 that sticks out: "I had never had a year like that in my life before or since." Having experienced the exceptional atmosphere at Carnegie, John has supported Carnegie for over 27 years.

John arrived at Carnegie with a B.S. in geology from Yale and was soon asked if he'd like to join other Carnegie scientists on a geology field trip out West. "It was the first time in my life that I had been treated like an adult." John had a crash course not just in geology, but in camping and even cooking. He drove back with staff scientist and future collaborator Frank Schairer, who "treated me as a colleague and a son." His work at the lab included the first synthesis, at 20,000 atmospheres of pressure, of a mineral ($CaAl_2SiO_6$), which was recently found in a meteorite and is now known as Kushiroite.

Unlike most academic settings, Carnegie was not constrained by hierarchy, and scientists "were able to follow their own stars." John believes that this is what allows Carnegie researchers to be their very best. He hopes that his annual support as a Barbara McClintock Society member allows early-career scientists to experience what he did in 1961: mentorship, confidence, and a new sense of purpose.

Other Individual Giving

Carnegie Science depends on and appreciates gifts at all levels and recognizes those who have contributed $9,999 or less this fiscal year. Thank you for your commitment.

$1,000 to $9,999

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Henry H. Arnhold
Cheryl A. Bantz
Robert and Lynne Barker
Charlotte S. Barus
Richard and Kathleen Becker
Ann Humason Bernt
Charles Bestor
Gregory C. Board
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Sigrid Burton and Max Brennan
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Rita and Jack* Colwell
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David Singer and Diana Kapp
Kimball D. Smith
Eric Smith and Polina Sokolova
Jordan Sorensen
Rebecca Stecker
George and Gretel Stephens
Douglas K. Struck

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"As we became new parents, it became increasingly critical to us to invest in a better future for our children."

Carnegie supporters Satyashree Srikanth (left) and Aparajit Raghavan (right)
Image courtesy Aparajit Raghavan

When Google engineers Aparajit Raghavan (right) and Satyashree Srikanth (left) began evaluating different organizations to support philanthropically, they were drawn towards opportunities to promote science. "As we became new parents," Satyashree explained, "it became increasingly critical to us to invest in a better future for our children." For these lifelong science enthusiasts, Carnegie's cutting-edge, entrepreneurial approach and passion for research made this institution a natural fit. Plus, Aparajit and Satyashree know that with Carnegie's low administration costs, their investment in the greatest scientific needs for the institution will be maximized, making their impact all the greater.

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Somu Sundaramurthy
David and Edie Tatel
Michael W. Thacher and Rhonda L. Rundle
John R. Thomas, Ph.D.
Ian Thompson
Peter Thompson
Scott B. Tollefsen
Lynette Trygstad
Peter E. van Keken
Cozette Vergari
Christopher Waid
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Promoting and supporting science has become a family affair. From left to right: sons Andrés and Daniel, husband and father Esteban Lizardo, son Gabo, and wife and mother Vannia De La Cuba.
Image courtesy Vannia De La Cuba

Vannia De La Cuba and her husband Esteban Lizardo began giving to the Carnegie Observatories in 2016, when John Mulchaey became Observatories director and began reaching out to the nearby Pasadena community. As both a long-time science enthusiast and a community field representative in District 5 of Pasadena—or as she and John joke, "the center of the universe of discoveries"—Vannia was a natural supporter of the Observatories.

"... there is **no more important investment** than in science."

Vannia and Esteban have three sons, and "science has been part of the family since the beginning." Daniel, now 25, is a materials engineer; Gabo, 22, is majoring in astrophysics at Columbia. Andrés, 14, follows in their footsteps with an engineering interest. Both older boys taught in a summer science program for elementary students, which Vannia had initiated. Speaking of her commitment to ensuring science education access to students throughout the Pasadena community, Vannia remarks, "We want the kids to say to themselves, 'Why can't I work at JPL?'"

According to Vannia, she and her husband chose to give as monthly sustainers "because it matters to me that I give back every month. It makes me feel better than I would once a year." This family feels that there is no more important investment than in science.

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Eric Schmidt (left) and Walter Isaacson (right) spoke at a public program held at Carnegie in November 2018.

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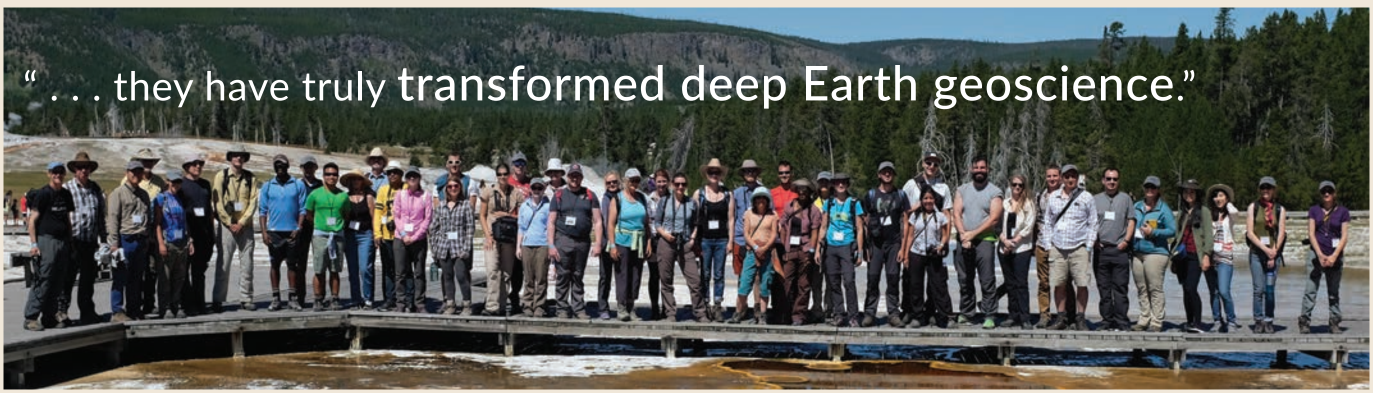

Early career scientists gather in front of a hot spring at the Deep Carbon Observatory Summer School in Yellowstone National Park in July 2016.
Image courtesy Katie Pratt/Deep Carbon Observatory

Ninety percent of Earth’s carbon lies in its deep interior, yet even as recently as ten years ago, we knew almost nothing of the planet’s deep carbon. We didn’t know how it moved between the mantle and crust, behaved in the crushing pressures and searing temperatures of the deep Earth, or affected the formation of methane, diamonds, or even life itself.

In 2009, the Alfred P. Sloan Foundation, one of the nation’s oldest private funders of science, and Carnegie Science came together to change that. We envisioned the Deep Carbon Observatory (DCO), a global, ten-year effort that would harness the collective knowledge, imagination, and passion of hundreds of geologists, physicists, biologists, and engineers and unite them in pursuit of a single goal: to revolutionize our understanding of Earth’s most important element.

Ten years later, the results speak for themselves. Headed by the DCO Secretariat at Carnegie and initiated by Carnegie staff scientist Robert Hazen, DCO has blossomed into an expansive collaboration of some 1,100 scientists across more than 50 countries. DCO scientists have published 1,300 papers, sent drones into the Fuego volcano in Guatemala and the Turrialba Volcano in Costa Rica, discovered 15 previously unknown carbon minerals, and uncovered new creatures in environments once thought too hostile to support life.

“The leadership of the Carnegie Institution and the hard work of more than a thousand DCO scientists around the globe is what has made the project such a success,” says Sloan President Adam Falk. “Together, they have truly transformed deep Earth geoscience.”

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Honors

Trustees and Administration

Former Carnegie fellow and current trustee **Sandra Faber** was selected to receive the 2018 American Philosophical Society's Magellanic Premium Medal. The medal is the nation's oldest for scientific achievement. It was established in 1786. It is awarded from time to time "to the author of the best discovery or most useful invention related to navigation, astronomy, or natural philosophy..."

Carnegie Trustee **Mary-Claire King** was awarded a 2018 Dan David Prize of the Dan David Foundation in Tel Aviv. It "recognizes and encourages innovative and interdisciplinary research that cuts across traditional boundaries and paradigms. It aims to foster universal values of excellence, creativity, justice, democracy and progress and to promote the scientific, technological and humanistic achievements that advance and improve our world."

Carnegie Academy for Science Education

The **DC STEM Network** is one of eight groups to win the US2020's 2018 STEM Coalition Challenge. The Challenge was a nationwide competition for communities to increase hands-on STEM mentoring and maker-centered learning to underrepresented students. The $1 million award will be shared by the groups to support further innovative, STEM-based learning for Washington, D.C., students. The Network is a collaboration between Carnegie Science's education arm, the Carnegie Academy for Science Education (CASE), and the D.C. Office of the State Superintendent of Education (OSSE). Marlena Jones of CASE is its director.

Embryology

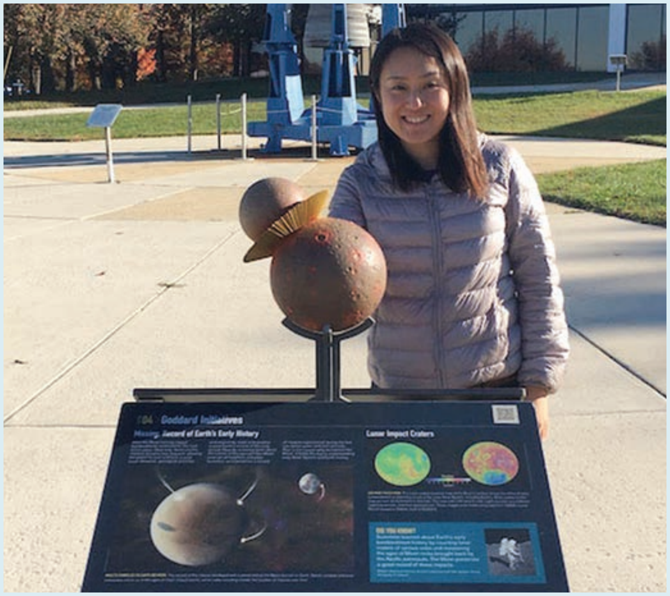
Allan C. Spradling, director emeritus of Carnegie's Department of Embryology, was awarded the 23rd March of Dimes and Richard B. Johnson, Jr., MD Prize in Developmental Biology as "an outstanding scientist who has profoundly advanced the science that underlies our understanding of prenatal development and pregnancy." Spradling and colleagues developed the fruit fly *Drosophila melanogaster* into a model for linking classical genetics with specific physiological processes for understanding human biology.

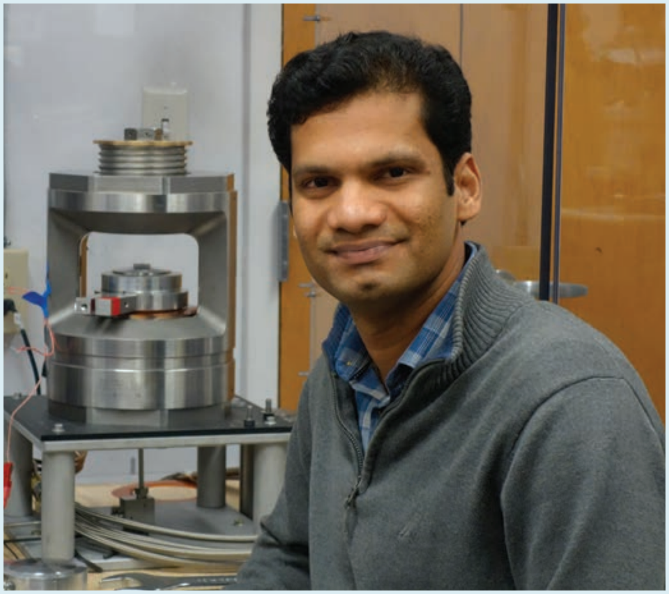
Global Ecology

Carnegie ecologist **Greg Asner** was awarded the 22nd Heinz Award in the Environment category in September 2017 by the Heinz Family Foundation. He was recognized for developing and using airborne and space-borne ultra-high-resolution imaging technology to reveal in unprecedented detail the health and biodiversity of the world's forests and coral reefs. His work has detailed the extent of deforestation, land degradation, and climate change throughout many regions of the world and is "helping to empower government agencies and nongovernment organizations, and to drive land use and environmental policy decisions in the United States and globally."

Eighth and Ninth Postdoctoral Innovation and Excellence Awards

The eighth and ninth Carnegie Postdoctoral Innovation and Excellence Awards (PIE) were given out this past year. These prizes are made through nominations from the departments and are chosen by the Office of the President. The recipients are awarded a cash prize for their exceptionally creative approaches to science, strong mentoring, and contributing to the sense of campus community.





Postdoctoral researcher at the Department of Terrestrial Magnetism (DTM) **Miki Nakajima** received the eighth PIE Award. Nakajima is a planetary geophysicist who joined Carnegie in 2015 from the California Institute of Technology, where she received her Ph.D. She uses computational methods to study the formation of planets and their satellites to predict the dynamics of planetary impacts and how impacts affect the young planetary objects. Her abilities transcend astronomy, geochemistry, and geophysics. She works across traditional disciplines within and outside the department. She has proven to be a valued member of the Carnegie community by organizing activities that range from annual poster sessions to interdisciplinary reading groups, and she serves as a postdoctoral representative.

Venkata Srinu Bhadram, a high-pressure researcher at the Geophysical Laboratory (GL), received the ninth PIE Award. He was the first to discover titanium pernitride (TiN_2) and cubic titanic nitride (Ti_3N_4), both long sought-after materials with great promise for future technological applications, among many other research achievements. He is also a stellar team player, generating new collaborations between GL and other groups to develop innovative solutions that have been driving research forward. He is also a dedicated mentor, teaching complex experimental methods and the underlying physical principles to students at the high school, undergraduate, graduate, and postdoctoral levels.

Transitions

Administration

Eric D. Isaacs began his tenure as the 11th president of the Carnegie Institution for Science on July 2, 2018, succeeding Matthew Scott who retired. Isaacs joins Carnegie from the University of Chicago where he had been the Department of Physics' Robert A. Millikan Distinguished Service Professor and the James Franck Institute Executive Vice President for Research, Innovation, and National Laboratories.

★ Eric D. Isaacs

Embryology

William Ludington joined the department staff in June 2018. He was the Bowes research fellow in the Department of Molecular Cell Biology at U.C.-Berkeley. His lab investigates complex ecological dynamics from microbial community interactions using the fruit fly *Drosophila melanogaster*. The goal is to understand the gut ecology and how it relates to host health, among other questions.

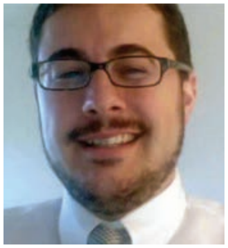
★ William Ludington

Observatories

Leopoldo Infante became the director of Las Campanas Observatory on July 31, 2017, succeeding Mark Phillips, now director emeritus. Infante had been the founder and director of the Centre for Astro-Engineering at Pontificia Universidad Católica de Chile. He also established the Chilean Astronomical Society (SOCHIAS) and served as its president from 2009 to 2010.

★ Leopoldo Infante

Nick Konidaris joined the astronomical staff at the Observatories in Pasadena. He is also Instrument Lead for the SDSS-V Local Volume Mapper (LVM). He works on a broad range of new optical instrumentation projects in astronomy and remote sensing, from experimental to large facilities.

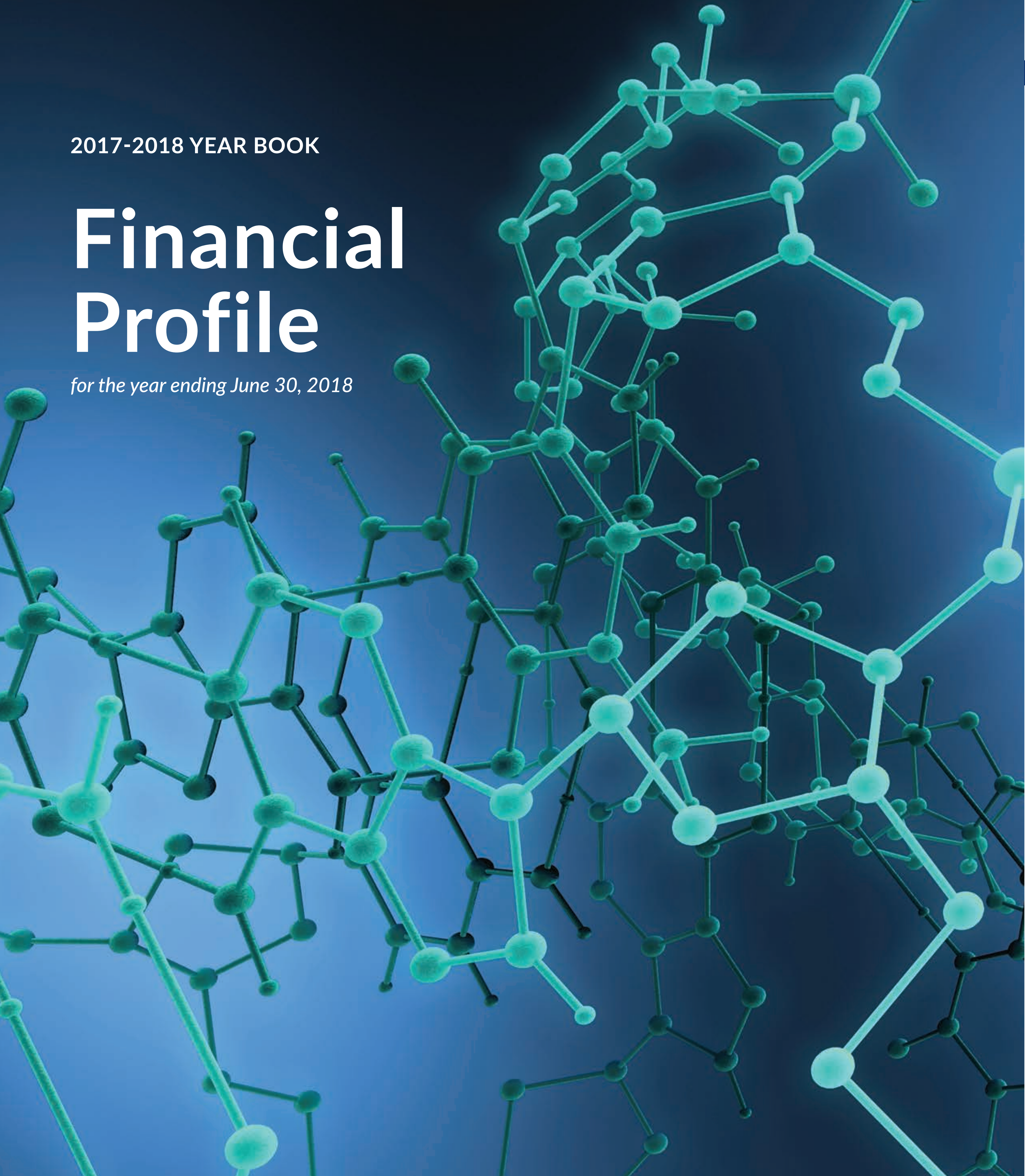


★ Nick Konidaris

2017-2018 YEAR BOOK

Financial Profile

for the year ending June 30, 2018



Reader's Note: *In this section, we present summary financial information. Each year the Carnegie Institution, through the Audit committee of its Board of Trustees, engages an independent auditor to express an opinion about the financial statements and the financial position of the institution. The complete audited financial statements are made available on the institution's website at www.CarnegieScience.edu.*

The Carnegie Institution for Science completed fiscal year 2018 in sound financial condition after generating a net return of 9% on the diversified investments within its endowment; maintaining a disciplined spending policy that balances today's needs with the long-term requirements of the institution and the interests of future scientists; and the continued support of organizations and individuals who recognize the value of basic science.

The primary source of support for the institution's activities continues to be its endowment. This reliance on institutional funding provides an important degree of independence in the research activities of the institution's scientists.

As of June 30, 2018, the endowment was valued at $996 million. Over the period 1998-2018, average spending rate of the endowment was at 5.0%. Carnegie closely controls expenses to ensure the continuation of a healthy scientific enterprise.

For several years, under the direction of the Investment committee of the board, Carnegie's endowment has been allocated among a broad spectrum of asset classes including: equities (stocks), absolute return investments, real estate partnerships, private equity, natural resources partnerships, and fixed-income instruments (bonds). The goal of this diversified approach is to generate attractive overall performance and reduce the volatility that would exist in a less diversified portfolio. In 2016 Carnegie hired its first Chief Investment Officer to more proactively steward the endowment's assets.

The Chief Investment Officer and Investment committee regularly examine the asset allocation of the endowment and readjust the allocation, as appropriate. The institution relies upon external managers and partnerships to conduct the investment activities, and it employs a commercial bank to maintain custody. The following chart shows the allocation of the institution's endowment among asset classes as of June 30, 2018.

Asset Class	Target	Actual
Common Stock	37.0%	38.7%
Alternative Assets	55.5%	55.5%
Fixed Income and Cash	7.5%	5.8%

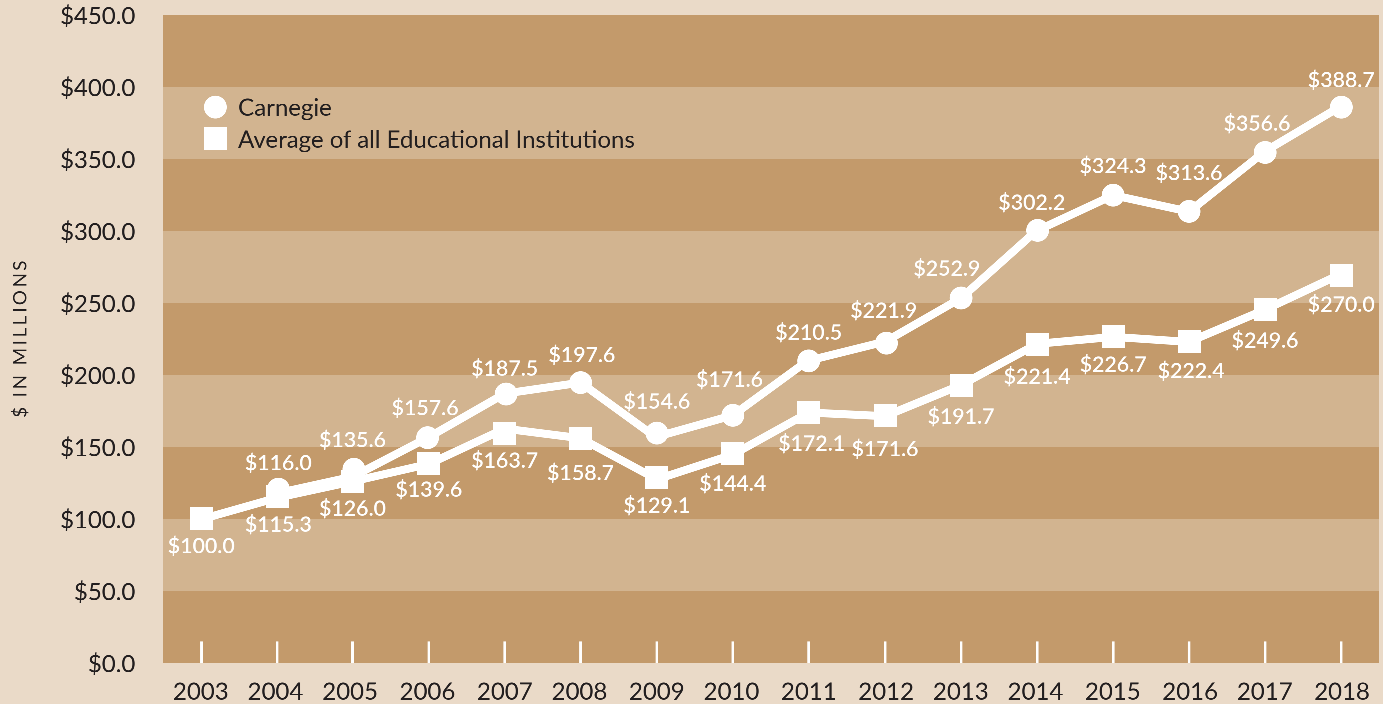
Carnegie's investment goals are to provide high levels of current support to the institution and to maintain the long-term spending power of its endowment. The success of Carnegie's investment strategy is illustrated in the first figure (right) that compares, for a hypothetical investment of $100 million, Carnegie's investment returns with the average returns for all educational institutions for the last fifteen years.

Carnegie has pursued a long-term policy of controlling its spending rate, bringing the budgeted rate down in a gradual fashion from 6+ % in 1992 to 5% today. Carnegie employs what is known as a 70/30 hybrid spending rule. That is, the amount available from the endowment in any year is made up of 70% of the previous year's budget, adjusted for inflation, and 30% of the most recently completed year-end endowment value, multiplied by the spending rate of 5% and adjusted for inflation and debt. This method reduces volatility from year-to-year. The second figure (right) depicts actual spending as a percentage of ending market value for the last 20 years.

In fiscal year 2018, Carnegie benefitted from continuing federal support. Carnegie received $17.9 million in new/additional federal grants in 2018. This is a testament to the high quality of Carnegie scientists and their ability to compete successfully for federal funds in this period of fiscal restraint.

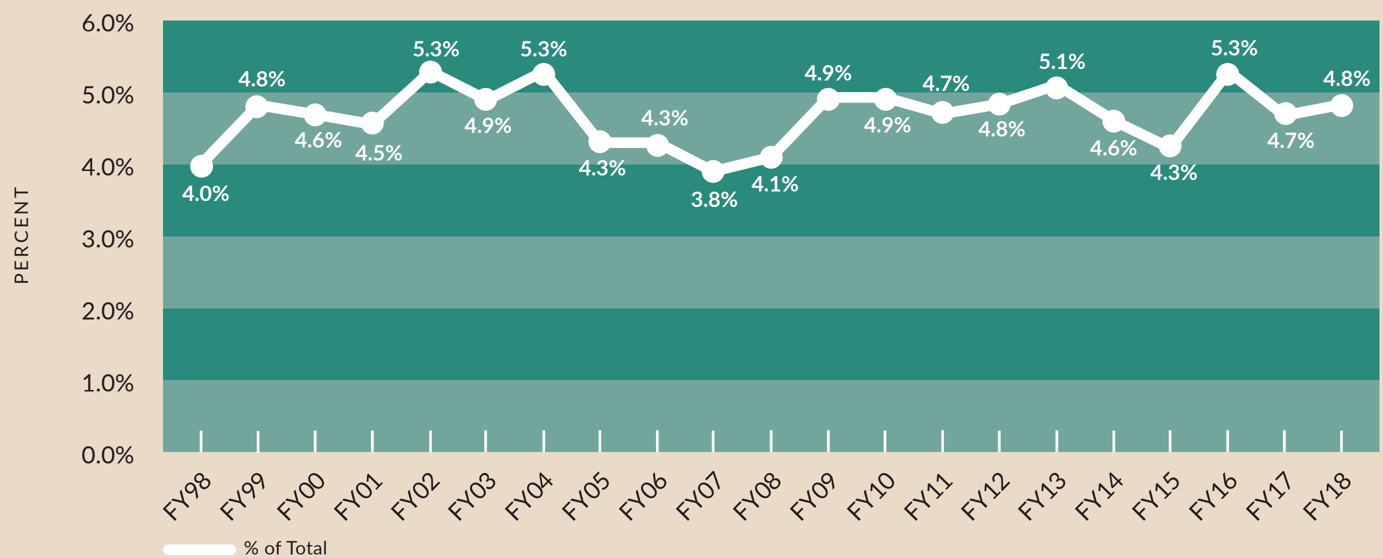
Carnegie also benefits from generous support from foundations and individuals. Funding from foundations has grown from an average of about $3 million/year in the period from 2000 to 2004 to $8.9 million in 2016. While there was a slight decline in 2017 and 2018, our private grant fundraising continues to be strong. Within Carnegie's endowment, there are several "funds" that provide support either in a general way or targeted to a specific purpose. The largest of these is the Andrew Carnegie Fund, begun with the original gift of $10 million. Mr. Carnegie later made additional gifts totaling another $12 million during his lifetime. This tradition of generous support for Carnegie's scientific mission has continued throughout our history and a list of donors in fiscal year 2018 appears in an earlier section of this year book. In addition, Carnegie receives important private grants for specific research purposes.

Illustration of $100 Million Investment — Carnegie Returns vs. Carnegie Average of all Educational Institutions (2003 - 2018)



Average returns for education institutions are taken from the NACUBO endowment study.

Endowment Spending Rate as a Percent of Endowment Value



Statement of Financial Position

June 30, 2018, and 2017

(in thousands)

	2018	2017
Assets		
Cash and cash equivalents	$ 18,761	$ 34,466
Contributions receivable	3,848	5,040
Accounts receivable and other assets (net)	7,307	6,306
Bond proceeds	21,306	20,319
Investments	996,497	947,231
Property and equipment (net)	132,309	133,422
Long-term deferred asset	59,324	58,188
Total assets	**$ 1,239,352**	**$ 1,204,972**
Liabilities		
Accounts payable and accrued expenses	13,706	17,671
Deferred revenue	27,504	27,685
Bonds payable	115,038	115,045
Accrued postretirement benefits	24,281	25,375
Total liabilities	180,529	185,776
Net Assets		
Unrestricted	322,559	308,316
Temporarily restricted	680,887	655,711
Permanently restricted	55,377	55,170
Total net assets	1,058,823	1,019,197
Total liabilities and net assets	**$ 1,239,352**	**$ 1,204,973**

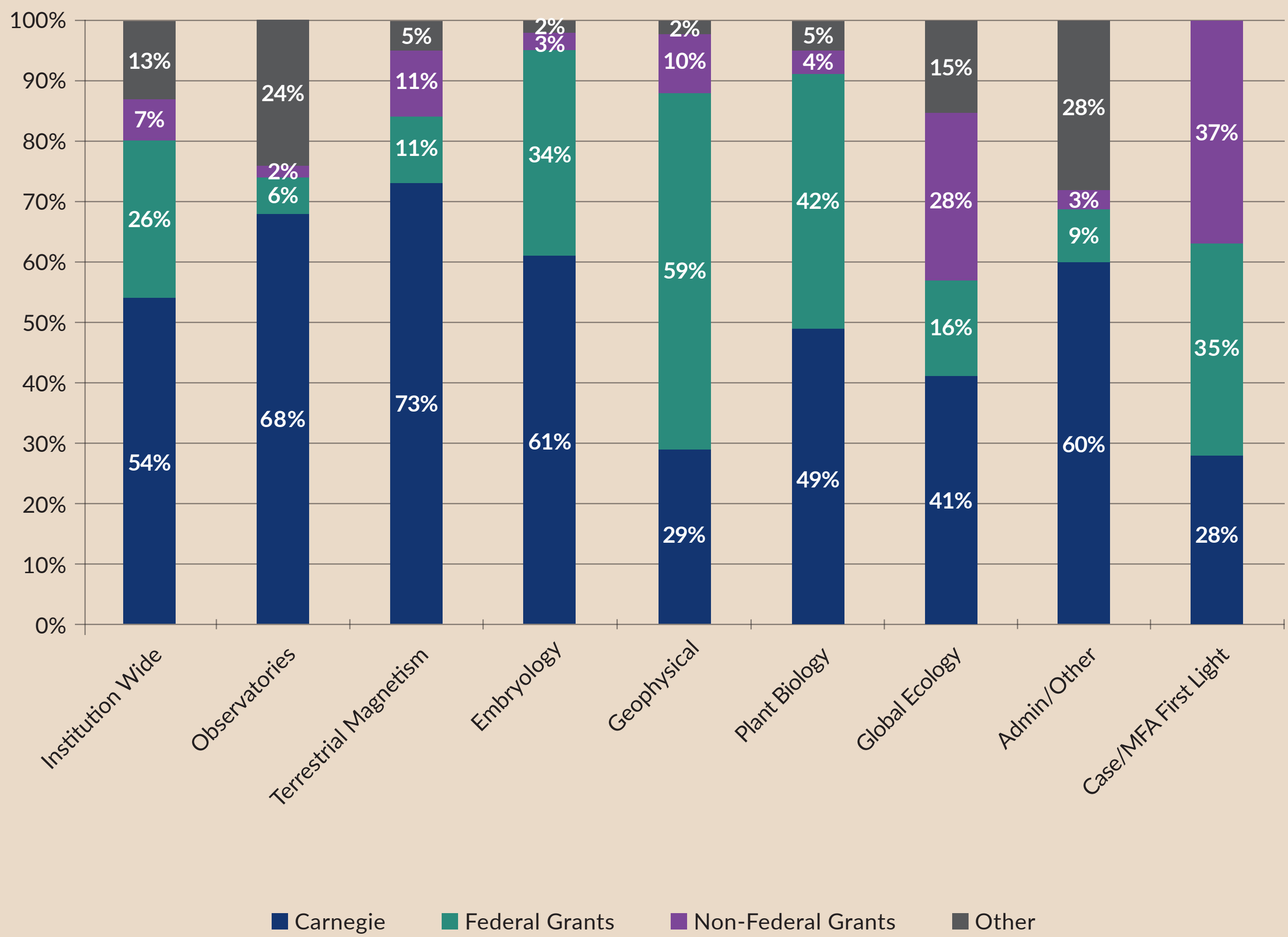
Statement of Activities

June 30, 2018, and 2017

(in thousands)

	2018	2017
Revenue and Support		
Grants and contracts	$ 26,907	$ 30,378
Contributions, gifts	7,681	8,847
Other Income	4,232	1,700
Net External Revenue	**38,820**	**40,925**
Investment income and unrealized gains	95,665	120,472
Total Revenue	**$ 134,485**	**$ 161,397**
Expenses		
Program and Supporting Services:		
Terrestrial Magnetism	9,882	9,723
Observatories	22,886	20,183
Geophysical Laboratory	19,711	20,587
Embryology	12,764	10,912
Plant Biology	10,118	11,330
Global Ecology	6,944	7,279
Other programs	849	648
Administration and general expenses	13,478	21,069
Total Expenses	**$ 96,632**	**$ 101,731**
Change in net assets before pension related changes	$ 37,853	$ 59,666
Pension related changes	1,773	3,345
Net assets at the beginning of the period	1,019,197	956,186
Net assets at the end of the period	**$ 1,058,823**	**$ 1,019,197**

Expenses by Funding Type by Department



Small, Lean, and Potent

Some 66 senior Carnegie investigators, with postdoctoral fellows and other colleagues, machinists, business administrators, facilities staff, and more contributed to 775 papers published in the most prestigious, peer-reviewed scientific journals during the last year. Many discoveries were widely covered by the media and had extensive social media reach.

For a full listing of personnel and publications see https://carnegiescience.edu/yearbooks

“Our findings suggest that as the core was extracted from the mantle, the mantle never fully mixed.”

COLIN JACKSON NEWSWEEK

Carnegie Investigators IN THE NEWS

“The mantle differentiation event preserved in these hotspot plumes can both teach us about early Earth geochemical processes and explain the mysterious seismic signatures created by these dense deep-mantle zones.”

BRADLEY PETERS UPI

“If each turbine removes something like half the energy flowing through it, by the time you get to the second row, you’ve only got a quarter of the energy, and so on.”

KEN CALDEIRA THE WASHINGTON POST

“When root growth slowed down, the root’s ability to respond to the direction of water was strongly diminished…the active process of water uptake by the root is necessary to see where water is in soil water and respond developmentally...”

NEIL ROBBINS PHYS.ORG

“While there's no comprehensive tally of algae outbreaks, many experts agree they're ‘quickly becoming a global epidemic.’ ”

ANNA MICHALAK CBS

"SDSS has been taking spectra in large swaths of the sky for a long time. But we are implementing new instrumentation that will allow us to do this 'continuously' across the sky."

JUNA KOLLMEIER FORBES

"… I just looked at my phone and I saw it was just covered with emails about a new source that was discovered by LIGO…My first thought was just, 'We're in the perfect position to try to find this.' "

BENJAMIN SHAPPEE, NPR

"As intriguing as it was to discover new extremes of chemical reactions, the researchers can't be entirely sure that they've solved the xenon mystery. Earth's core was not under such high pressures when the planet first formed…"

ALEXANDER GONCHAROV FOX NEWS

"It was the universe's last major transition and one of the current frontiers of astrophysics. Gathering all this mass in fewer than 690 million years is an enormous challenge for theories of supermassive black hole growth."

EDUARDO BAÑADOS NEWSWEEK

"For our study what we were trying to do is reach single-cell resolution—that is, track how transposons moved through cells on an individual basis…"

ZHAO ZHANG POPULAR SCIENCE


CARNEGIE SCIENCE
obs.carnegiescience.edu @CarnegieAstro

« THE OBSERVATORIES »

Astronomy

Pasadena Staff—Front row (left to right): Leon Aslan, Andrew Benson, Luis Ochoa, Greg Ortiz, Jerson Castillo, Robert Storts, Christoph Birk. Second row: Thomas Connor, Solange Ramirez, John Mulchaey, Gillian Tong, Linnea Dahmen, Sunny Rhoades, Gwen Rudie, Regina Lee, Stephanie Striegel, Sal Fu. Third row: Kristin Macklin, Daniel Kelson, Rosalie McGurk, Charlie Hull, Cynthia Hunt, Jeffrey Crane, Becky Lynn, Alan Uomoto, Sung-Ri Sok, Nicholas Konidaris, Beverly Fink, Andrew Newman, Jorge Estrada, Chelsea Adelman. Last row: Patricio Jones, Eduardo Bañados, Stephen Shectman, Stefano Pasetto, Yuan-Sen Tin, Nicole Relatores, Alexander Ji, Andrew McWilliam, Terese Hansen, François Schweizer, Scott Rubel, Vincent Kowal, Michael Rauch, Jeffrey Rich, Earl Harris, Joshua Simon, Irina Strelnik, Brian Lorenz, Sergio Escobar.

Image courtesy Scott Rubel

Carnegie Investigators

Staff Scientists

ANDREW BENSON
REBECCA BERNSTEIN
ALAN DRESSLER, Staff Member Emeritus
JUNA KOLLMEIER
NICHOLAS KONIDARIS [1]
PATRICK MCCARTHY
ANDREW MCWILLIAM
JOHN MULCHAEY, Director
ANDREW NEWMAN
AUGUSTUS OEMLER, JR., Director Emeritus
ERIC PERSSON, Staff Member Emeritus
ANTHONY PIRO [2]
GEORGE PRESTON, Director Emeritus
MICHAEL RAUCH
GWEN RUDIE
FRANÇOIS SCHWEIZER, Staff Member Emeritus
STEPHEN SHECTMAN
JOSHUA SIMON
IAN THOMPSON
RAY WEYMANN, Director Emeritus

Research Associates

CHRISTOPHER BURNS, Research Associate
JEFFREY CRANE, Staff Associate
DAN KELSON, Staff Associate
BARRY MADORE, Senior Research Associate

Las Campanas Research Staff

LEOPOLDO LIRA INFANTE, Director, Las Campanas Observatory [3]
DAVID OSIP, Associate Director, Las Campanas Observatory
MARK PHILLIPS, Director Emeritus, Las Campanas Observatory [4]

Las Campanas Resident Astronomer

NIDIA MORRELL, Resident Astronomer

[1] From October 1, 2017
[2] From November 1, 2017, formerly Hale Scholar/Staff Associate
[3] From August 1, 2017
[4] From August 1, 2017

« LAS CAMPANAS »

Mountain staff (left, front row left to right: Javiera Rey, Perla Pommer, Yuri Beletsky, Pedro Tirado. Second row: Francesco Di Mille, Mauricio Navarrete, Armando Rodriguez, Francisco Mery, Jorge Bravo, Patricio Pinto, Leopoldo Infante. Third row: Miguel Ocaranza, Luis Gonzalez, Jorge Rojas, Manuel Traslaviña, Pedro Carrizo. Fourth row: Jorge Olivares, Erwin Guerra, Jose Cortes, Andres Rivera, Carlos Weinberger, Marcelo Rodriguez, Juan Espoz N., Consuelo Gonzalez, Sergio Veliz, Juan Gallardo, Rodrigo Condore, Ricardo Alcayaga, Victor Meriño. Last row: Nelson Ibacache, Felipe Sanchez, Luis Calderon, Andres Borquez, Herman Olivares, David Verdugo, Jose Luis Zamora, Edgar Veliz, Oscar Duhalde.

Chilean Staff— El Pino (right, front row left to right): Roberto Bermudez, Silvia Muñoz, Konstantina Boutsia, Nelda Juica, Ivan Barraza. Second row: Lionel Zumaran, Jonathan Medalla, Carlos Martin, Jaime Gomez, Leopoldo Infante.

Carnegie Investigators

Staff Members

- ALEX BORTVIN
- DONALD D. BROWN, Director Emeritus
- CHEN-MING FAN
- STEVEN A. FARBER
- JOSEPH G. GALL
- MARNIE E. HALPERN
- WILLIAM LUDINGTON [1]
- ALLAN C. SPRADLING, Director Emeritus
- YIXIAN ZHENG, Director [2]

Staff Associates

- CHRISTOPH LEPPER
- ZHAO ZHANG

[1] From June 18, 2018
[2] Served as interim co-president from December 2017-June 2018

« THE DEPARTMENT OF EMBRYOLOGY »

Genetics/Developmental Biology

Front row (left to right): Ed Hirschmugl, John Urban, Steve Farber, Allan Spradling, Yixian Zheng, Joseph Gall, William Ludington, Chen-Ming Fan, Dianne Williams, Rejeanne Juste, Patricia Cammon. Second row: Brandie Dobson, Sammasia Wilson, Chiara De Luca, Myriam Alexander-Kearns, Lauren Gilmer, Meredith Wilson, Jui-Ko Chang, Yun Bai, Anwen Shao, Zheng-an Wu, Lynne Hugendubler, Lu Wang, Jung-Hwa Choi, Amanda Chicoli, Sonya Bajwa, Glenese Johnson. Third row: Kevin Smolenski, Ted Cooper, Sungjin Moon, Carol Davenport, Allison Pinder, Michelle Macurak, Ethan Greenblatt, Wilbur Ramos, Pedram Nozari, Valerie Butler, Monica Hensley, Liang-Yu Pang, Semen Vlasov, Asia Davidian, Jean-Michael Chanchu, Svetlana Deryusheva, Jen Anderson, Mira Sohn. Forth row: Devance Reed, Robert Vary, Daphne Deshields, Jiaxiang Tao, Claire Mical, Emma Spikol, Wanbao Niu, Han Xiao, Kun Dou, Tabea Moll, Michelle Biederman, Maggie Shen. Last row: John Halpin, Mahmud Siddiqi, Jay Thierer, Aki Ohdera, Bob Levis, Mehran Esteghamat-Rad, Tyler Harvey, Michael Sepanski, Minjie Hu, Lu Wang, Aiden Danoff, Chenhui Wang, Marla Tharp, Joseph Tran, Katherine Cox, Vladimir Shiriagin, Vanessa Quinlivan, Frederick Tan, Xiaobin Zheng.

Image courtesy Jeremy Hayes, Carnegie Institution for Science

Earth/Planetary Science and Astronomy

Front row (left to right): Wan Kim, Kevin Johnson, Richard Carlson, Steven Golden, Lara Wagner *(and Winston her dog)*, Janice Dunlap, Hélène Le Mével, Quintin Miller. First row standing: Shaun Hardy, Roberto Molar Candanosa, Fouad Tera, Scott Sheppard, Mary Horan, Adriana Kuehnel, Susana Mysen, Alycia Weinberger, Sanni Turunen *(visiting student from University of Helsinki, Finland)*, Merri Wolf, Parvin Zahedivash, Conel Alexander, Larry Nittler, Peter van Keken. Second row standing: John Chambers, Brian Schleigh, Gary Bors, Paul Butler, Steve Shirey, Alan Boss, Tim Mock. Third row standing on the ledge: Cian Wilson, Emily Cahoon *(visiting Ph.D. student from Portland State University)*, Jianhua Wang, Jaehan Bae, Sharon Xuesong Wang, Meredith MacGregor, Jonathan Tucker, Doug Hemingway, Elodie Brothelande, Asaf Gelber *(Geochemical Society)*, Kathleen McKee, Jessica Arnold, Anaïs Bardyn, Maximilien Verdier-Paoletti, Kei Shimizu, Megan Newcombe, Helen Janiszewski, Tim Jones, Peter Driscoll, Diana Roman.

Merle A. Tuve Senior Fellow

MICHAEL R. PERFIT, Distinguished Professor of Geology, Department of Geological Sciences, University of Florida, Gainesville[1]

MORRIS PODOLAK, Professor of Planetary Sciences, Tel Aviv University[2]

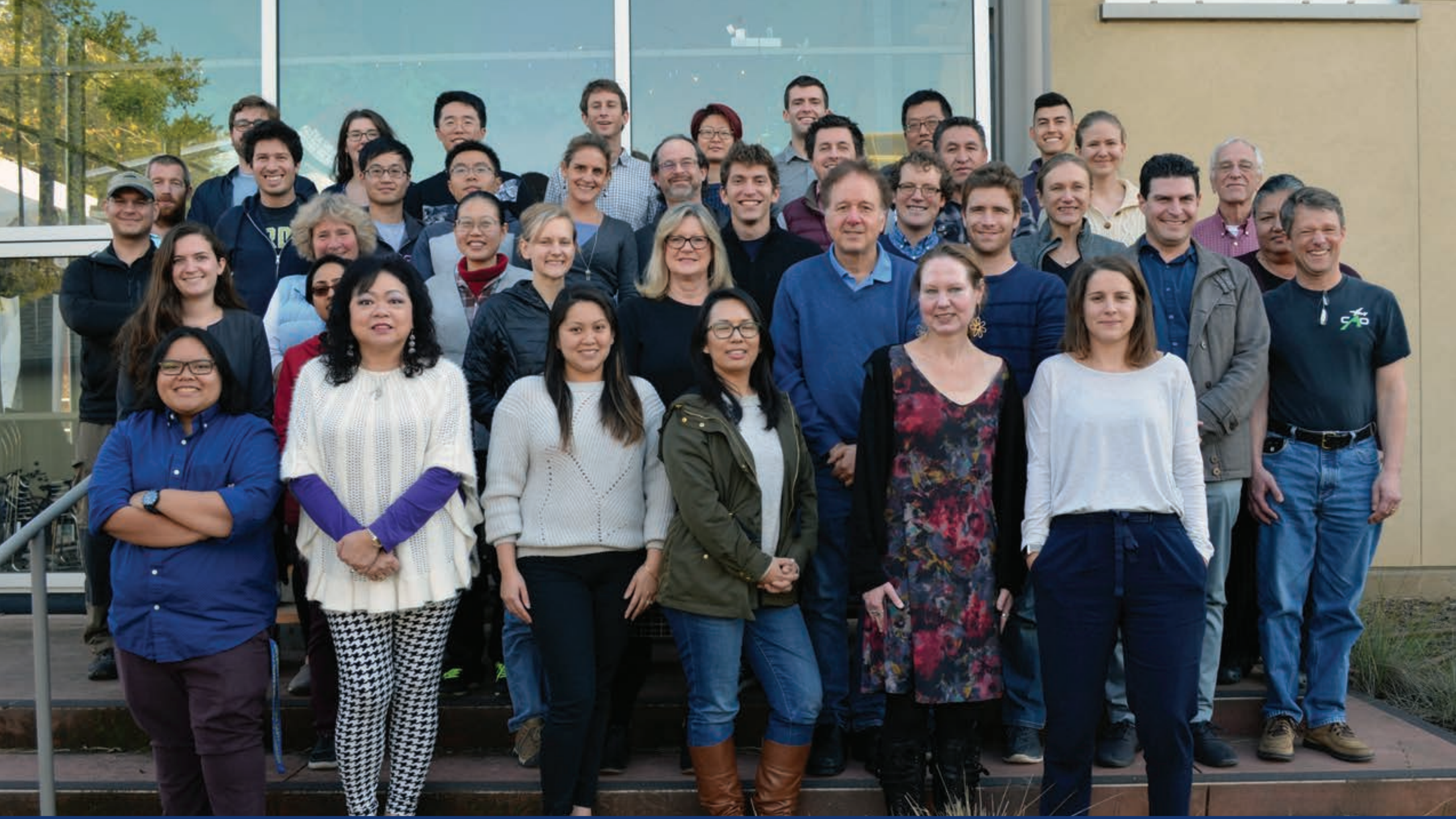
ALBRECHT W. HOFMANN, Emeritus Director, Max Planck Institute for Chemistry; Adjunct Professor at Lamont-Doherty Earth Observatory and the University of Nanjing[3]

Carnegie Investigators

Research Staff Members

- CONEL M. O'D. ALEXANDER
- ALAN P. BOSS
- R. PAUL BUTLER
- RICHARD W. CARLSON, Director
- JOHN E. CHAMBERS
- PETER E. DRISCOLL
- JOHN A. GRAHAM, Emeritus
- ERIK H. HAURI
- HÉLÈNE LE MÉVEL
- ALAN T. LINDE, Emeritus
- LARRY R. NITTLER
- DIANA C. ROMAN
- I. SELWYN SACKS, Emeritus
- SCOTT S. SHEPPARD
- STEVEN B. SHIREY
- SEAN C. SOLOMON, Director Emeritus
- FOUAD TERA, Emeritus
- PETER E. VAN KEKEN
- LARA S. WAGNER
- ALYCIA J. WEINBERGER

[1] From October 3, 2017, to November 24, 2017 [2] From January 1, 2018, to March 1, 2018 [3] From May 15, 2018, to June 9, 2018



Carnegie Investigators

Staff Scientists

GEORGE D. CODY
RONALD E. COHEN
YINGWEI FEI
ALEXANDER F. GONCHAROV
ROBERT M. HAZEN
HO-KWANG MAO
BJØRN O. MYSEN
DOUGLAS RUMBLE III
ANAT SHAHAR
ANDREW STEELE
TIMOTHY A. STROBEL
VIKTOR V. STRUZHKIN
MICHAEL WALTER, Director[1]

[1] From April 2, 2018

« THE GEOPHYSICAL LABORATORY »

Matter at Extreme States, Earth/Planetary Science

Front row (left to right): Amol Karandikar, Fei Yingwei, Steven Bassin, Douglas Rumble, Michael Walter, Ho-Kwang (Dave) Mao, Eugene Gregoyanz *(visitor)*, Timothy Strobel, Md. Mijanur Rahaman, Quintin Miller. Second row: George Cody, Anat Shahar, Michael Guerette, Dhiren Phadhan, Li Zhu, Peng Ni, Dyanne Furtado, Emma Bullock, Stephen Elardo, Lin Wang, Andrew Steele, Alexander Goncharov, Aline Niyonkuru. Third row: Irina Chuvashova, Jennifer Mays, Victor Lugo, Dionysis Foustoukos, Jeff Lightfield, Robert Hazen, Zackary Geballe, Olivier Gagné, Yanhao Lin, Andrea Mangum, Merri Wolf, Bjørn Mysen, Gary Bors, Gabor Szilagyi, Amanda Lindoo, Teerachote Pakornchot, Matthew Ward, Reinhard Boehler, Seth Wagner. Last row: Trong Nguyen, Mingguang Yao *(visitor)*, Adelio Contreras, Craig Schiffries, Joseph Lai, Teresa Fornaro, Nivea Magalhaes *(visitor)*, Shaun Hardy, Michelle Hoon-Starr, Marilyn (Helen) Venzon, Jing Yang, Agnes Mao, Suzy Vitale, Wan Si Tang, Svetlana Shkolyar, Asmaa Boujibar, Catharine Conley *(visitor)*, Mary Ferranti, Takehiko Yagi *(visitor)*.

Global Ecology

Front row (left to right): Maria Lopez, Evana Lee, Jessie Chen, Ngoc Ho, Clare Tuma, Clara Garcia Sanchez. Second row: Clare LeDuff, Eva Sinha, Emily Francis, Elizabeth Susskind, Ken Caldeira, Patrick Brown, Michael Mastrandrea, David Knapp. Third row: Garret Huntress, Terri Tippets, Bingwen Qui, Phil Brodrick, Leander Anderegg, Anna Michalak, Naoia Williams. Fourth row: James Askew, Lei Duan, Yelu Zeng, Manoela Romano de Orte, Ari Kornfeld, Ovidiu Csillik, Ismael Villa, Jennifer Johnson, Joe Berry. Last row: Theo Van De Sande, Danny Cullenward, Rachel Engstrand, Yixuan Zheng, David Koweek, Mengyao Yuan, Tristan Ballard, Jiwei Li, Yoichi Shiga.

Carnegie Investigators

Research Staff Members

GREGORY ASNER
JOSEPH A. BERRY, Acting Director
KENNETH CALDEIRA
ROBIN MARTIN
ANNA MICHALAK

« CARNEGIE SCIENCE »

Administration

Front row (left to right): Abbey Sevcik, Jessica Moore, Maggie Drain, Jillian Rivera, Michelle Scholtes, Alexis Fleming, Eric D. Isaacs, Lara Budeit, Shanique Washington, Dina Freydin, June Napoco-Soriente, Tamar Lolua, Rosi Vela. Second row: Emily Williams, Koki Hurley, Tonya Phoenix, Ann McElwain, Brian Loretz, Tony DiGiorgio, Ana Lojanica, Giovonti Vick, Tina McDowell, Tim Doyle, Yolanda White, Zulma Amaya, NaDaizja Bolling, Don Brooks, John Strom, Ben Aderson. Last row: Zach Nelson, Ben Barbin, Margaret Moerchen, Fahim Siddiqi, Shawn Frazier, Quintin Miller, Loronda Lee, Michael Pimenov, Shaun Beavan, Quinn Zhang, Yang Kim.

Senior Administrative Staff

ERIC D. ISAACS, President
TIMOTHY DOYLE, Chief Operations Officer
ANN MCELWAIN, Chief Development Officer
MICHAEL STAMBAUGH, Chief Investment Officer
BENJAMIN ADERSON, General Counsel
MARGARET MOERCHEN, Science Deputy to the President

Plant Science

Front Row (left to right): Sue Rhee, David Ehrhardt, Zhiyong Wang, Angelica Vasquez, Maria Lopez, Renate Weizbauer, Justin Findinier. Second row: Evana Lee, Jiaying Zhu, Yuchun Hsiao, Xuelian Yang, Hannah Vahldick, Veder Garcia. Third row: Naoia Williams, Diane Chermak, Weichao Huang, Zhenzhen Zhang, Mackenzie Machado, Efren Gonzalez. Fourth row: Kate Stevenson, Heather Meyer, Kangmei Zhao, Jacob Moe-Lange, Wenfei Wang, Yang Bi. Fifth row: Emanuel Sanz-Luque, Katie Magallon, Yue Rui, Suryatapa Ja, Angela Xu, Jessie Chen. Sixth row: Matt Evans, Karine Prado, Ying Sun, Navadeep Boruah, Chan Ho Park, Charles Hawkins, Cheng Zhao. Seventh row: Tuai Williams, Frej Tulin, Rick Kim, Rajnish Khanna, Winslow Briggs, Heather Cartwright, Chuan-Chih Hsu, Ngoc Ho. Eighth row: Weimin Ni, Haojie Jin, Fan Lin, Tamara Vellosillo, Nienke Bresbrugge, Bo Xue, Garret Huntress, Ismael Villa, Antony Chettoor. Last row: Kevin Radja, Neil Robbins, Theo Van De Sande.

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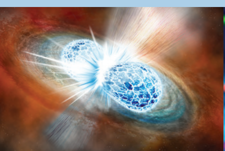




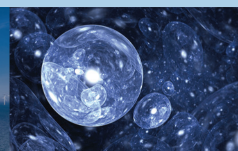
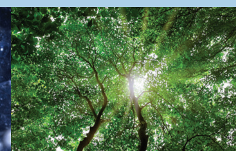

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